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THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE

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EMPIRE SUGAR

A. C. MASON

THE Chadbourne Plan was an attempt to reduce the unsaleable stocks of sugar in the world, and, by restoring a healthy balance of supply and demand, to raise world prices to an economic level. Owing largely to the United States and the countries of the British Empire not being parties to the Convention, and to the growing economic nationalism which narrowed the unprotected 'free' market, these aims were not fully realized. Sugar stocks were indeed, reduced; but prices remained and still remain obstinately low. The Convention was allowed to lapse at the end of the five years agreed upon. The hope of rationalizing the supply and distribution of sugar in the world now rests on the outcome of an International Sugar Conference, at which all the countries concerned are to be represented, which it is proposed should be convened at an appropriate moment by the Government of the United Kingdom. Preliminary discussions have been carried to an advanced stage, and though it is still uncertain whether, in view of recent Supreme Court decisions regarding agricultural policy, the United States are yet ready to participate, the prospects of the Conference are hopeful. The discussions at such an International Conference could not fail to have a profound influence on the relations between producing and consuming countries generally, and hence upon the relations of the sugar-surplus countries of the Empire with their preferential markets in Great Britain and Canada.

The following notes summarize the situation as it appears in the various sugar-producing regions of the Empire, on the eve of the suggested International Conference, the countries being taken in geographical order from Fiji in the east to British Guiana in the west. They are naturally concerned in the main with the producers of cane sugar, whose almost universal dilemma is the necessary increase of production for technical and economic reasons, while the scope of the market available for them is inevitably limited. From the present point of view the problems of the beet-sugar industries in the temperate Empire countries are relatively unimportant, and they have not been discussed. Except in so far as the recent settlement of the U.K. beet-sugar industry tends to simplify eventual negotiations, its details are rather of local significance, and they have consequently been omitted.

Fiji

Like other sugar-growing countries in the Empire, Fiji shows a strong tendency to increase production above the pre-War level:

TABLE 1. *Production of Sugar in Fiji*

Year	*Tons*	*Year*	*Tons*
1913–14	92,112	1933–4	116,113
1931–2	79,725	1934–5	112,806
1932–3	135,241	1935–6 (estimate)	127,000

The crop is grown for export and manufacture is in the hands of the Colonial Sugar Refining Company, Ltd., the largest of the Australian sugar firms. Rather more than half the exports go to Great Britain and rather less than half to Canada. Up to a few years ago, Canada was the chief market. Nearly the whole of the export to Great Britain consists of the Colony's quota (44,000 tons) for the special preference granted to Empire sugar. The continued low price of sugar makes it necessary for exports to be sent to preferential markets. The crop is produced by peasant farmers, the estate system having become unsatisfactory since immigration from India ceased in 1916. Over three-quarters of the cane is produced by Indians, but the quantity grown by Fijians is increasing. Research into fertilizers, biological control of insect pests, and cultivation practices have been carried on by the Company's Officers for many years. New varieties of cane are tested for suitability to the soils and climates of various districts.

Fiji is capable of expanding its sugar output, but is restrained by the unremunerative level of world prices. Indeed, if the value of receipts were to fall further, the Company might be tempted to give up its Fijian interests altogether. As sugar is the mainstay of the island agriculture, the maintenance of at least the present value of the industry is of the greatest importance.

Australia (*Queensland*)

Apart from an annual production of about 30,000 t. of cane sugar in New South Wales and about 5,000 t. of beet sugar in Victoria, the Australian sugar crop is grown in Queensland. The progress of the Queensland sugar industry may be summarized as follows:

TABLE 2. *Production of Sugar in Queensland*

Year	*1,000 acres harvested*	*1,000 t. cane yielded*	*1,000 t. raw sugar produced*	*Tons of sugar per acre*	*Tons of cane to 1 ton of sugar*
1900	73	848	93	1·27	9·17
1914	108	1,923	226	2·09	8·51
1925	189	3,668	486	2·56	7·55
1926	189	2,953	389	2·06	7·59
1927	204	3,556	486	2·38	7·32
1928	216	3,736	521	2·41	7·18
1929	215	3,581	519	2·41	6·91
1930	222	3,529	517	2·33	6·83
1931	233	4,034	581	2·49	6·94
1932	205	3,546	514	2·51	6·90
1933	228	4,667	639	2·80	7·31
1934	218	4,270	613	2·80	6·97
1935*	..	4,190	605	..	6·93

* Estimates.

These figures show that the scope of the sugar industry in Queensland was practically trebled during the first 30 years of this century. The yield of cane has fluctuated, owing largely to the vagaries of climate, but

that of sugar has increased fairly steadily, from 1·27 t. per acre in 1900 to 2·56 t. in 1925, and 2·80 t. in 1933 and 1934. Improved field practice and mill efficiency, the greater use of irrigation, better knowledge and application of fertilizers, the more general planting of disease-resistant and high-yielding cane, all tend to increase the average production of sugar per acre and, on the whole, to bring down overhead costs, unless the grower's output falls below a certain minimum, which must increase as the value of sugar falls.

In too many cases, this economic minimum output is not being attained. Sugar is the chief field crop of tropical Queensland, the population of which has more than doubled since the War—between 1921 and 1933 it increased from 45,000 to 97,000. Sugar occupies 20 per cent. of the cultivated land, and sugar-cane accounts for 60 per cent. of the value of agricultural production and 20 per cent. of all the commodities produced. The number of immigrant growers is increasing, and provision must also be made for members of the farmers' families, but no more Government land is available for starting new farms. Hence the average size of the holding tends to diminish faster than the average yield increases, so that average production falls. The grower is bound to deliver all his cane to a particular mill and no mill is allowed to exceed its previous 'peak year' output. As the number of growers in a given district increases, the quota of each farmer supplying the mill must fall.

The total output which can be divided among the mills is limited by the size of Australian consumption and the amount that can be exported. The home market is reserved for Australian sugar and absorbs about 320,000 t., or 60 per cent. of the output, the official price being well above the world-market level. The remaining 40 per cent. is exported, chiefly to Great Britain and Canada, where it enjoys preferential treatment under existing trade agreements. The British rebate of 3*s.* 9*d.* per cwt. will continue, under the Ottawa Agreement, till August 1937.

The central problem from the Australian point of view is the disposal of excess sugar, and it is important that the existing demand should be maintained and if possible increased. Growers would doubtless prefer a moderate sacrifice of output in addition to the restriction which they have accepted since 1930 under the 'peak year' scheme to the ruinous competition with which they are faced.

At the end of 1935, the Federal Parliament passed the Sugar Agreement Bill, which continues the embargo on imports and the fixed-price system in Australia for another five years. The general effect is to stabilize conditions over a reasonably long period, in so far as purely Australian action can do so, and to keep sugar production well under control. The hand of the Commonwealth Government will thus be strengthened for future discussions with the United Kingdom and in any International Sugar Conference that may be called.

In Australia, as in so many Empire countries, technical advances are making for increased production, whilst economic considerations set a higher limit to the total output and a lower limit to the crop of the individual farmer. The problem is one of resolving the apparent contradictions of these tendencies.

India

By far the greater part of Indian production consists of *gur* or *jaggery*, an imperfectly refined form of sugar for local consumption. A small proportion of this is used for making white sugar, though this branch of the industry is declining, and a certain amount of low-grade white sugar is made by the open-pan or *Khandsari* process. Since 1931, modern factories for the manufacture of white sugar direct from cane have increased rapidly, under the protection of the customs tariff.

TABLE 3. *Production of Gur and White Sugar in India 1929–30 to 1935–6*

	1929–30	*1934–35*	*1935–6*
	(*Thousand tons*)		(*Est.*)
Gur for consumption as such . .	1,837	3,500	4,000
Khandsari	200	150	125
White Sugar refined from *gur* .	21	40	40
White Sugar made in modern factories direct from cane . . .	90	578	684

TABLE 4. *Production of White Sugar direct from Cane, 1925–6 to 1935–6*

Seasons	*Factories working*	*Cane crushed* (*tons*)	*White sugar produced* (*tons*)	*Recovery* (*per cent.*)
1925–6	23	659,406	52,990	8·03
1926–7	25	742,368	62,941	8·47
1927–8	26	786,476	67,684	8·60
1928–9	24	791,361	68,050	8·59
1929–30	27	989,776	89,768	9·07
1930–1	29	1,317,248	119,859	9·09
1931–2	32	1,783,499	158,581	8·89
1932–3	57	3,350,231	290,177	8·66
1933–4	112	5,157,373	453,965	8·80
1934–5	130	6,672,030	578,115	8·66
1935–6 (estimates)	140	9,780,000	885,000	9·05

The establishment of a sugar-refining industry originated in the application of scientific methods to sugar-cane problems early in the present century. The growing-season in India was short, the yield was low, the quality of cane poor, and the land-tenure system generally opposed to the formation of compact estates where the best methods could be practised. The need was for a more robust, early-ripening cane, and for a higher yield of sugar. As a result of suggestions made by the Board of Agriculture in 1911, the Coimbatore Cane-Breeding Station began its work, under the late Dr. Barber.

The outstanding services rendered by Coimbatore are probably the following:

(*a*) The discovery of the importance of the wild *Saccharum Spontaneum*, or *Kans* grass, as a parent for hybrid seedling-canes for North India, and the application of this and of the subsequent discovery of *Kassoer* cane.

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ERRATA

In Vol. IV, p. 292, last line of Table 3, *for* 684 *read* 885;
p. 295, line 12 of text, *for* 180 t. *read* 20 t.

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(*b*) The establishment of the importance of the cane root-system and the study of this subject.

(*c*) The differentiation on the basis of root-system between 'noble' tropical canes and the native canes of sub-tropical India.

(*d*) The production of inter-generic hybrids between *Sorghum* and sugar-cane, with a view to early maturity.

It is claimed that there is now a Coimbatore variety specially suited to practically every Indian sugar area. The breeding of sugar-cane–sorghum hybrids is continued on a wide scale, and promising seedlings can now be sent to out-stations and thus tested in different climatic and other conditions. Thick or noble varieties are being bred, some to obtain types for semi-irrigated conditions and some to suit the drier regions of South India. Intensive studies in morphology and cytology and extensive soil surveys are in progress. Canes are, in general, being bred to increase their resistance to disease, to secure the erect habit of growth, and to develop rind hardness as a protection against insects and rats.

In 1911, the yield of cane per acre was about 10 t.; the sugar-content was about 6 per cent.; mature canes, fit for crushing, were available for about 70 days in the season; the area under canes was 2,215,000 acres; the yield of *gur* 2,218,000 t., that of sugar under 15,000 t. Hardy varieties of cane, with hard rinds, resistant to insects and to mosaic disease, and thus suitable for improved yields under village conditions, are now common. The area under cane amounts to about 4,000,000 acres; yields are from 20 to 35 or more tons per acre: recovery is at the rate of 10 or more per cent. in many areas; the crushing season may last from November to April. The application of scientific methods to Indian sugar has, in fact, been successful, and the fiscal protection granted in 1931 is no more than a stage—though a most important one—in the progress of India from being a deficit to becoming a self-supporting country.

The indigenous demand for *gur* will always be satisfied from home-grown cane. In the five years 1927–31, India's annual consumption of factory sugar was about 962,000 t. The increase of consumption depends on the general prosperity of the country.

Disasters like the Bihar earthquake have retarded progress. Insect infestation in the United Provinces has caused doubts—happily not confirmed—as to the possibility of continuing the sugar crop there. These and other adverse factors, such as the uncertainty of cane supplies and the uneconomically small capacity of many mills, have slowed down the expansion of the output and the stage of complete self-sufficiency has not yet been reached. India has, however, been almost entirely withdrawn from the world market. The significant fact is that a large quantity of sugar formerly exported to India must now find other outlets or must cease to be produced. The whole structure of the world's sugar trade and in particular that of Java is thereby modified.

Mauritius

Before 1928, Mauritius was an exporter of white sugar, mainly to Great Britain. The British tariff arrangements made in that year

changed the character of the industry by greatly increasing the proportion of the crop exported in the form of raw sugar. The amount produced does not, as in so many other Empire countries, show any tendency to increase:

TABLE 5. *Production of Sugar in Mauritius (metric tons)*

Season	*Tons*	*Season*	*Tons*
1913–14	249,705	1932–3	247,220
1928–9	253,430	1933–4	261,460
1929–30	238,030	1934–5	178,860
1930–1	220,960	1935–6 (estimate)	263,000
1931–2	164,010		

The effect of the British tariff on the character of the exports is clearly shown in the percentages of raw and 'vesous' (i.e. refined) sugar, which between them account for over 98 per cent. (of recent years over 99 per cent.) of the total. From 1925 to 1927 the average percentage of sugar exported as 'vesous' was 98. From 1928 it declined to 11·8 in 1934 and 20·6 in 1935, the remainder being exported as 'raws'.

Apart from the necessity for meeting the change indicated above, Mauritius has had to contend with a succession of difficulties. Before the War, the chief adverse factor was infestation by the destructive beetle *Phytalus Smithi*, which was first discovered on sugar-canes in 1911. Action against this pest is still one of the main preoccupations. The War boom brought prosperity and this made great local improvements possible, but the post-War slump and a succession of climatic difficulties have reduced the industry to great straits. It is only this season that Mauritius begins to get the better of these cumulative disasters, by the aid of grants from Imperial funds.

A Sugar-Cane Research Station was established in 1929. The chief entomological problem is the control of *Phytalus Smithi*. Other research activities include cane-breeding, investigations on the root-system of the sugar-cane, variety yield trials, and manurial experiments.

The scientific and technical side of the industry is well in hand; its major difficulties are economic. To maintain the level of exports to the United Kingdom is of great importance from the island's point of view.

Union of South Africa

Under the stimulus of fiscal protection, the production of sugar in Natal and Zululand has been increasing since 1903, when a customs convention of all South African States discriminated against sugar from Mauritius and other oversea sources, in favour of the home industry. In the decade 1923–32, the acreage reaped in Zululand increased from 26,400 to 52,000 (97 per cent.) and that in Natal from 60,000 to 88,000 (46 per cent.). The cane crushed increased from 2·15 million tons in 1926–7 to 3·87 million tons in 1934–5. The production of sugar in recent years is shown opposite:

TABLE 6. *Production, Imports, and Exports of Sugar (short tons)*

Year	*Production*	*Net imports*	*Exports of South African produce*	*Retained available for consumption*
1925–6	239,851	6,075	70,602	175,324
1926–7	242,662	4,091	66,910	179,843
1927–8	247,273	5,292	68,978	183,587
1928–9	295,934	25,261	96,681	224,514
1929–30	298,635	15,746	123,590	190,791
1930–1	393,205	6,004	210,632	188,577
1931–2	325,933	4,154	146,977	183,110
1932–3	358,905	820	185,451	174,274
1933–4	391,173	1,226	190,811	201,588
1934–5	358,738	..	..	..
1935–6 (est.)	420,000	..	..	..

The cane usually grown is Uba, which is resistant to drought and to mosaic disease. It is, however, difficult to harvest, contains much fibre and other impurities, and has recently become liable to 'streak', a virus disease resembling mosaic. In 1926, steps were taken to clear the sugar areas of all canes liable to mosaic. Between Jan. 1927 and Dec. 1930, the growing of canes other than Uba (except in quarantine) was prohibited, the object being not so much to encourage Uba as to make way for the introduction of better varieties not subject to mosaic or streak. Successive releases of Java and Coimbatore canes have been made from the Experimental Station of the South African Sugar Association, which is supported by the industry without Government funds. The new varieties can yield 180 t. of cane and 2 t. of sugar per acre. The two local enemies of the crop are drought and locusts.

As in Australia, the danger of over-production is the chief economic problem of the industry. The steps taken to deal with it also resemble those taken to deal with a similar danger in Australia. The situation had become acute by 1934, when the Minister of Commerce and Industries started an inquiry into the working of the sugar industry. In Sept. 1935 a Conference was summoned by the Minister to consider the results of his inquiry, and a Committee was set up to consider schemes for improvement. The discussions were inconclusive and a special Conference was called at Durban in March 1936 to evolve a definite scheme, failing which the Government was prepared to take control of the industry. The outcome was the Fahey Conference Agreement, which lays down the lines of future policy. Its main provisions include the limitation of total production to 476,488 t. annually, the establishment of a Central Board of Control and an equalization fund, and the unification of growing and refining in a single industry.

In fixing the amount of total production, the Conference had in mind both the requirements of the South African market, and the possibility that, as the result of the impending International Sugar Conference, South Africa's quota for export to Great Britain might not exceed 224,000 short tons. Certain millers and cane-growers claimed the right to expand their output to an 'economic' figure, a demand which again

recalls Australia. The Conference fixed maximum production at the probable South African consumption five years hence. The quotas of individual mills on this basis will be brought into conformity with market requirements by *pro rata* reductions each year. The simplification and control attained by this measure will tend to strengthen the hands of the Union Government in the coming discussions.

British Tropical America

The outstanding fact about the British West Indies and British Guiana is the steady increase of production, due in great measure to the improved varieties of cane and the better field and mill practices resulting from scientific progress. In the last quarter of a century, production in the region as a whole, which was not affected by the Chadbourne Scheme, has practically doubled, in spite of adverse conditions. In some islands (e.g. Barbados, St. Kitts) the output has been trebled, although the area under cane has changed little. In Jamaica the crop has increased fivefold. Even if the economic incentives had been the same, such a striking expansion would scarcely have been possible, unless a great advance in sugar-cane technique had been made. Pre-War results are compared with the most recent estimates in the following summary table:

TABLE 7. *Production in British Tropical America (tons)*

	*1935–6**	*1934–5*	*1933–4*	*1913–14*
Trinidad	131,000	117,786	105,342	55,488
Barbados	100,000	46,412	82,934	33,387
Jamaica	85,000	76,753	72,528	15,583
Antigua	21,000	17,700	20,677	15,345
St. Kitts	25,000	28,491	28,262	8,655
Other B.W.I.	8,000	9,175	6,730	7,799
Total, B.W.I.	370,000	296,317	316,473	136,257
British Guiana	130,000	125,000	132,240	106,211
Grand total, British Tropical America	500,000	421,317	448,713	242,468

* Estimates.

After the reorganization of the Barbados Department of Agriculture in 1925, it was possible to apply on a larger scale recent knowledge and technique, and to rely more and more on deliberate rather than on fortuitous crosses. Other West Indian Islands had not made the same progress, but the new varieties of Barbados canes selected for the very diverse local conditions by trial and error were in great demand. By 1930, over 77,500 acres had been planted with Barbados canes, in addition to 35,000 acres in Barbados itself. At the Imperial Sugar-cane Research Conference in 1931, proposals were made for the planned breeding of canes, specially suited for the needs of the separate islands, and the British West Indies Central Sugar-cane Breeding Station was accordingly established in Barbados in 1932.

Investigations into fertilizers and into the biological control of insect

pests are associated with the introduction of more suitable canes. Trinidad may be quoted as an example of the way in which the three main problems—cane-breeding, fertilizers, entomology—grow up together. The destruction caused by the froghopper insect (e.g. in 1917, when it is estimated that 10,000 t. of sugar were lost through the pest) led, in 1921, to the appointment of a special committee. They started entomological research, with which the name of Dr. Myers is associated. It was soon found that the work had to be expanded to comprise a comprehensive scheme of investigation, including soil surveys, cane ecology, and fertilizer experiments in addition. Apart from this scheme, long-term fertilizer experiments are being carried out by the Imperial College of Tropical Agriculture, in conjunction with Imperial Chemical Industries. Among the many schemes of research now in progress are those relating to cane-breeding, fertilizers, and entomology, which have been continuous in British Guiana also for many years.

The outcome of the efforts which have been and are being made is that the replacement of unsuitable by suitable canes, the better utilization of the soil, the protection of the growing crop, and the making of the final product have been systematized for the whole of this area. Yields which twenty years ago would have been regarded as distinctly good are now looked on almost as crop failures; but the market on which this greatly increased production must be sold is restricted.

In spite of the generous treatment which West Indian sugar now receives in the U.K. and Canada, its two chief markets, the continued depression of the world price reduces the value of the preference to the West Indian producer. In most of the islands, sugar is either the only crop that is grown for export or the best alternative. This goes far to explain the effort to increase production, which meets a limiting factor in the world price of sugar.

In the autumn of 1935, a delegation of the Barbados Legislature visited England, to bring to the notice of the British Government 'the precarious outlook of the only industry of importance in the island'. Sugar is the only crop grown for export, either as raw sugar or (on account of the low sugar price) as fancy molasses. The market for the latter—Canada—is, however, limited.

The population of over 1,000 per sq. mile, depending chiefly on the sugar industry, would be reduced to destitution if it collapsed. The same is broadly true of Antigua and St. Kitts. In both Jamaica and Trinidad considerable areas are still available for cane-growing, and it is probable that they will be used, since the expansion of the sugar industry seems to be essential. The Panama disease of bananas in Jamaica and the witch broom disease of cacao in Trinidad render an alternative crop an urgent necessity. In British Guiana, where conditions differ from those of the islands, the severe drought of 1934, followed by abnormal rainfall, greatly retard the increase of production; but here, too, more sugar is being produced.

The more sugar the West Indies and British Guiana produce, the more they must export to the U.K., and the greater becomes the pressure on the London terminal market, so that the price must continue low. The

main problem of British Tropical America is thus to expand the preferential market for its sugar and sugar products such as molasses and rum.

Canada

Like the United Kingdom, Canada maintains a beet-sugar industry, but draws most of her supplies from abroad. Empire countries producing cane sugar enjoy fiscal preference and contribute about 90 per cent. of the imports. The readjustment of British preferential duties in 1928 has caused the relative importance of the British West Indies and British Guiana to increase. Of 359,000 t. of Empire sugar imported in 1932, 189,000 t. came from the West Indies; of 312,000 t. imported in 1933, 129,000 t. were from the West Indies, and 185,000 out of 292,000 t. imported in 1934. In 1935, the West Indies again increased their share, whilst both British Guiana and Mauritius sent considerably more than in 1934.

The relative importance of home and imported supplies is shown below:

TABLE 8. *Canada—Home and Imported Supplies of Sugar (tons)*

Year	*Consumption of imported sugars (raw value)*	*Production of refined sugar from home-grown beet*
1930	400,098	42,243
1931	403,753	47,830
1932	368,945	58,936
1933	346,045	58,675
1934	377,987	50,894
1935	416,028	67,000

While the beet sugar industry is expanding, it provides only a small proportion of the total supply. The significance of Canada, from the standpoint of Empire sugar, is rather as a preferential market for the product of the neighbouring Colonies. Consumption is increasing, after declining for a few years, and was 10 per cent. greater in 1935 than in 1934. The demand for Colonial raw sugar may, accordingly, be expected to increase also.

United Kingdom

Besides providing a market for the greater part of the raw sugar exported from Empire countries, the U.K. is itself a considerable producer of beet sugar. British supplies of raw sugar are drawn from all the chief producing countries and the London terminal market practically determines the price of non-protected sugar and hence the world sugar price, upon which the various preferential prices are based. The capacity of the British market to absorb the surplus sugar of Empire countries is limited by the trend of consumption in the U.K., the needs of the refiners beyond the level of immediate consumption, the size of the home beet-sugar crop, and the amount drawn from non-Empire sources.

Since the War, a beet-sugar industry has been built up in England and Scotland with the aid of a subsidy. After prolonged discussions, the eighteen factories refining beet-sugar have been brought together, under the Sugar Industry (Reorganization) Bill, into a Corporation,

somewhat like a public utility company. A Sugar Commission has been appointed to act as an administrative body, interposed between the Corporation and the growers of sugar-beet. The total area for beet-growing contracts is to be determined each year by the Commission, in such a way as to limit the production of white sugar to 560,000 t.

The part played by home-grown beet sugar in the building up of supplies for British consumption is shown in the following comparison:

TABLE 9. *U.K. Consumption of Imported and Home-grown Sugar (Raw Value). (Tons)*

	Imported	*Home-grown*	*Total*
1935	*(1,604,678)	*(611,092)	2,215,770
1934	1,653,616	545,080	2,198,696
1933	1,673,289	421,428	2,094,717
1932	1,819,164	277,992	2,097,156
1931	1,811,281	405,797	2,217,078
1930	1,728,318	382,563	2,110,881
1929	1,775,219	251,171	2,026,390
1928	1,811,223	199,202	2,010,425

* Provisional.

In the past seven years, the total consumption of sugar in the U.K. has risen by 200,000 t., but that of home-produced beet has in the same period risen by over 300,000 t., so that the market for imported sugar has been, on balance, restricted. If consumption continues to expand, the stabilization of the home beet-output will cause a corresponding expansion of the demand for imports. Part of this demand will be met from foreign sources, the remainder from Empire countries. The elasticity of this part of the British demand is a measure of the extent to which the output of Empire producers can safely be increased.

Under the 1926 Finance Act, the preferential duties on Empire sugar were stabilized for a period of ten years. This period has been provisionally extended till August 17, 1937. In 1934, modifications were introduced into the preference for Colonial sugar, whereby a special reduction of duty amounting to 3*s.* per cwt. was granted on an annual total of 360,000 t., which was divided among the colonies concerned by a system of quotas. The preferences granted to S. Africa and Queensland were fixed for a period of five years under the Ottawa agreement. These agreements end on August 17 and June 30, 1937, respectively.

All Empire suppliers aim, naturally, at making sure of their quotas in any new agreement that may result from the proposed International Sugar Conference. The settlement regarding the beet-sugar industry frees the hands of the United Kingdom to some extent for negotiations at an eventual conference. The impending termination of the present Empire preferences at much the same date frees them still more; and the relations of the sugar-exporting Empire countries to their customers (mainly the U.K.) are thereby put in a better way of being stabilized on a fresh basis.

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RECENT EXPERIMENTS ON MANURING *HEVEA* AND THEIR BEARING ON ESTATE PRACTICE

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WITH PLATE 16

I. *Summary*

THE paper describes the reasons why *Hevea* plantations grow increasingly in need of nitrogenous manuring with advancing age, and why the results of changes of vigour are but slowly reflected in the yields. The earlier published results are surveyed, including the classic case of Grantham's experiments in Sumatra.

The results of a large number of experiments carried out in the last five or six years are presented and discussed, and lead to the following conclusions:

1. In mature rubber nitrogen is usually the only element required for rejuvenation by manuring. Organic forms of fertilizer have not justified their extra cost over sulphate of ammonia during the period of five years.

2. Yield-response may be rapid in rubber which has been backward, if it is still fairly young, but in old rubber response is usually slow. Two stages of recovery may be noticed, the first being associated with the quick recovery of foliage and the second with the slower improvement in bark. Expenditure may result in profitable return in from one to seven years, and during this time the capital value of a stand is much enhanced.

3. It is shown that the economic value of manuring depends not only on the arrest of deterioration, but also in bad cases upon definite movement of yields towards recovery.

4. The growth-rate of the trees provides a useful criterion for judging the degree of starvation and the frequency of application required. It is tentatively suggested that quick response is likely to be obtained where the growth-rate of the trees has fallen below a standard girth-increment of half an inch per year.

5. Young rubber on replanted sites will seldom do well without manuring, and mineral elements are required to support nitrogen. Complete fertilizers should, therefore, be given until it can be proved whether one of the mineral elements can safely be omitted.

Exceptional cases are dealt with, and comments made on outstanding questions related to manuring, such as the uses of natural undergrowth and the treatment of *Oidium* leaf-disease.

II. *Introduction*

During the earlier period of the development of *Hevea* plantations little attention was given to manuring. Virgin soils were available and the results were naturally good, whilst large profits were so easily earned

that no emphasis was laid upon refinements in methods of cultivation. At later stages, however, visible deterioration in the trees made it plain that ameliorative treatment was required, but at the same time periods of financial difficulty tended to delay action. Manuring of rubber has, therefore, not yet established itself as a general practice, at least in Malaya, though it is now widely realized to be a growing necessity for the adequate upkeep of estates.

The subject is one of many intricacies, but for a broad survey it will suffice to grasp a very few outstanding features. These are concerned firstly with soil changes and secondly with the peculiarly slow response of the trees. During the early development of the industry, clean-weeding became established as a fixed rule in cultivation, the chief reasons being ease of supervision and the fear of weed-competition, which was observed to have marked effects on the growth-rate of young trees. Under the system of clean weeding the changes in the soil followed a definite course of deterioration from clearing onwards: exposure caused the top soil to be lost by erosion; the loose physical texture and consequent good drainage to be lost by compacting; and the nitrogen cycle to be thrown out of balance by raised temperature, oxidation of humus being increased and renewal from falling debris being reduced. The most usual history has, therefore, been the satisfactory establishment of a well-grown stand of trees at first, followed by a gradual deterioration in which nitrogen starvation is the main characteristic. The well-established root-system precludes mineral deficiencies from becoming marked at later stages. The symptoms of mineral deficiency may be seen, however, on sites which were under cultivation before rubber was planted, but there the limitation has been present from the outset, leading to a special type of stunted growth which is usually known by the descriptive name 'orchard type'. A great deal of the most backward rubber in Malaya is on sites with such a history. Thus we have to consider two types of stand and their associated manuring problems, firstly, the restoration and maintenance of yields from well-grown rubber of good yield in the past but now more or less deteriorated, and, secondly, the stimulation of stunted, backward rubber of the orchard type.

It should be said in passing that replanting with high-yielding clones is in general a much more promising alternative than the manuring of old stands of trees, but the incidence of restriction regulations on replanting, not to mention the large capital cost, still enforces the consideration of rejuvenating treatments.

Although for many crops we have well-established knowledge of the benefits of manuring, it is difficult and even misleading to attempt to argue too closely from analogy when considering the manuring of rubber. The physiological functions of the latex are still only guessed at, and it is not yet possible to suggest fertilizer treatments designed specifically to stimulate the secretion and flow of latex. One difficulty in that direction is that sometimes increased flow may be observed from causes which are antagonistic rather than beneficial to the health of the tree, and it is worth while remarking that inverted behaviour of this

kind may possibly be at the bottom of much of the confusion at present unresolved in experimental results on manuring. Our consideration must, therefore, be limited to the general question of maintaining vigour with the expectation that yields will be closely related. The crop is drawn by various systems of tapping as a continuous drain on the trees with gradual excision of the bast of the bark, usually taking one-half the circumference for each 'panel'. The ultimate continuity of yield depends upon the renewal of the bark as a natural recovery from tapping, and the usual consumption of about 9 in. of bark per year allows anything up to ten years for this renewal between successive tapping cycles. It will appear from the results discussed in this paper that manuring would greatly relieve the difficulties which have led to growing conservatism about bark-consumption in recent years. But the point which we wish to bring out here above all others is the time lag which this dependence upon slow bark-renewal introduces between cause and effect when yield-changes are under consideration.

Setting aside yield-differences due to inherent character, the yield from a tree depends upon (1) the vigour of the tree, and particularly the depth and extensiveness of the root-system—a factor which might be loosely referred to as sap-pressure; (2) the quality of the bark under tapping, and (3) the height of the tapping-cut above the roots and its position in relation to the boundary scars of previous tapping panels. Under starved conditions the first factor may be affected by the reduced transpiration due to sparseness of leaf, whilst the second factor is affected by the poor bark-renewal, giving rise to thin hard bark, the unevenness of which is much increased by the greater incidence of cambial wounding and callous-formation. A stand of trees will sometimes become so static in growth that the normal girth-increment (which should go on regularly during the whole life of the tree) is hardly measurable over a period of years. The normal growth for untapped trees with plenty of space is over 2 in. per annum. Trees on plantations will commonly slow down to a rate of $\frac{3}{4}$ in. or less as a result of the inevitable crowding and of the drain on vigour and restrictions on sap-movement due to tapping. The renewal of bark if growth stops becomes purely a wound recovery, whereas normally the renewal depends very much on the processes of girth-expansion. This wound-recovery is most active during the first months after tapping. It is, therefore, clear that the condition of a particular region of bark under tapping, which has during its renewal integrated the changes of growth over a period of perhaps eight years, will depend largely upon the nutritional status ruling long before. Hence there is a great lag between the beginning of starvation and its final result in diminishing yields. This fact, more than any other, has caused the prevalent delay in taking the necessary action by manuring. It dominates the situation not only by presenting cases where deterioration is advanced before action is taken, but also by delaying the full manifestation of yield-benefits until long after the trees have been themselves improved by the application of fertilizers. For this reason experiments need to be conducted over the period of a full tapping-cycle before the complete story can be

unfolded, and much promising work has been prematurely abandoned for lack of early result.

III. *Survey of Earlier Results*

The classic example of rubber manuring is the well-known experiment of Grantham on the H.A.P.M. estates of Sumatra [1, 2, 3, 4]. When the last returns were published this experiment had been running for 13 years. Since it provides the longest and most complete set of published data available and affords a good illustration of general points the main results are tabulated below in Table 1.

Grantham's Experiment on White Soil

The experiment began in March 1919 on an area of young mature rubber just 8 years old. The soil was a white loam peculiar to the east coast of Sumatra and known to be particularly poor in plant-food. On this type of soil the general experience had been that rubber grew well for the first 5 or 6 years, but that then rapid deterioration set in. The experiment was laid out on $\frac{3}{4}$-acre plots arranged as a 'chessboard' with 8 replications of each treatment, 5 series of plots with different manurial treatments being included. Two of the treatments (B and D) were not absolutely consistent during the first few years, but the other three remained almost unchanged throughout the course of the experiment. These were A = Control, C = 5 lb. per tree of nitrate of soda (1·75 lb. N) annually, and E = 4 lb. per tree of sulphate of ammonia (0·82 lb. N) biennially. Later on, the two remaining series were brought into a regular manuring scheme, B = the full dressing of sulphate of ammonia (4 lb. per tree) annually, and D = half-dressings of sulphate of ammonia biennially. Preliminary experiments had shown that nitrogen was by far the most important demand, and this was borne out by the earlier results from series B and D where the addition of phosphate ('ammophos' and superphosphate) and lime (calcium cyanamide) did not in any way enhance the effect of nitrogen alone. Superphosphate actually appeared to cause a slight depression of the yield of series D in 1920. The annual yields of all five series were as follows:

TABLE 1. *Grantham's Manurial Experiment with* Hevea *on White Soil*

Age of trees	*Period*	*Yield of dry rubber in lb. per acre*[1]					*Percentage comparison (Yield of control = 100)*			
		A	*B*	*C*	*D*	*E*	*B*	*C*	*D*	*E*
8–9	1919–20	279 (O)	340 (N)	321 (N)	302 (N)	292 (O)	122	115	108	105
9–10	1920–21	310 (O)	398 (O)	393 (N)	325 (P)	353 (N)	128	127	105	114
10–11	1921–2	180 (O)	281 (O)	354 (N)	237 (N)	283 (O)	156	197	132	157
11–12	1922–3	298 (O)	401 (O)	533 (N)	382 (O)	465 (N)	135	179	128	156
12–13	1923–4	171 (O)	257 (O)	422 (N)	251 (N)	352 (O)	150	247	147	206
13–14	1924–5	255 (O)	346 (NP)	535 (N)	368 (O)	466 (N)	136	210	144	183
14–15	1925–6	268 (O)	356 (O)	550 (N)	392 (½N)	473 (O)	133	205	146	177
15–16	1926–7	258 (O)	354 (N)	580 (N)	392 (O)	505 (N)	137	225	152	196
16–17	1927–8	307 (O)	426 (N)	672 (N)	472 (½N)	574 (O)	139	219	154	187
17–18	1928–9	361 (O)	531 (N)	764 (N)	530 (O)	671 (N)	147	212	147	186
18–19	1929–30	358 (O)	546 (N)	757 (N)	525 (½N)	656 (O)	153	211	147	183
19–20	1930–1	334 (O)	521 (N)	709 (N)	489 (O)	608 (N)	156	212	146	182
20–21	1931–2	363 (O)	615 (N)	725 (N)	534 (½N)	611 (O)	169	200	147	168

[1] The symbol in brackets indicates the nature of the fertilizer applied each year, the unit dressing being about 0·8 lb. N per tree.

Annual dressings of nitrogen gave the quickest and best response, series C rising gradually from an initial yield of 320 lb. per acre in 1919–20 to a maximum of over 760 lb. per acre 10 years later (1928–9), at which time the control Series (A) was giving only 360 lb. per acre. The yield of Series C actually reached almost double the yield of the control in the third year and has exceeded this ratio since the fifth year. Biennial dressings of nitrogen (Series E) gave a similar though slightly smaller response, reaching a maximum of 670 lb. per acre in the tenth year. The initial level of these plots was rather below that of Series A, and from the economic point of view the experiment showed that full biennial dressings were quite sufficient, whilst half-dressings biennially (Series D) were definitely too small. The experiment did not bring out any difference between the various forms of nitrogen. The yield-level of the control has increased slightly with age (from 280 lb. per acre in 1919–20 to just over 360 lb. in 1931–2), but the appearance of the trees is reported to be deplorable with die-back in an advanced stage and exceedingly poor bark-renewal. As a result of this experiment, an expanding manurial programme was begun in 1921 on the H.A.P.M. estates and continued in 1923–6. Some 85 per cent. of the total area of these estates was situated on white soil and yielding originally 300 lb. per acre, and during this period the average yield of the estates rose steadily to about 475 lb. per acre as a result of manuring.

Grantham's first report appeared in 1924 [1] and the interest aroused by his experiment led many other people to put down manurial experiments on rubber on a number of different soil types. Many of these experiments were not so carefully planned as Grantham's, and failure to get so striking or immediate a response resulted in the premature abandonment of a great number of them. This applies particularly to Malaya, where fewer properly designed experiments were put down in the earlier years and where later the world economic crisis of 1931 caused a drastic curtailment of expenditure on all estates.

Other Manurial Experiments in Sumatra

In 1926 Schmöle [5] published a résumé of over 50 trials and experiments on estates along the east coast of Sumatra, and showed that although manuring with nitrogen gave improvement on white soils, often indicated at once by the better appearance of the trees and sometimes amounting to as much as 10–20 per cent. increase in yield in the first year, a similar response was seldom, if ever, obtained on the red soils. Most of these experiments had been continued for only a very short period at the time of the report, and thus the evidence from them was not really conclusive. Grantham himself had laid down several experiments with different fertilizers on various soil types in 1918. These experiments had been carried on for 16 months but had given little or no response within that period, with the exception of a slight increase in the yield of most of the nitrogen series during the last few months. They were not continued in view of the quicker response obtained with nitrogen on the white soils.

Manurial Experiments in Java

In 1931 van Heusden and Vollema [6] described some experiments in Java on young backward rubber and showed that whereas nitrogen alone produced practically no result, a very marked effect, both on appearance and girth-increment, was obtained with a complete fertilizer (NPK). Although the trees were already about 5 years old when the experiments were started, they were able to demonstrate that the manured trees were ready for tapping at least a year earlier than the control. Ament [7] also reported a number of experiments on young rubber which gave various results with NPK, some showing accelerated growth and others no result.

Later, in 1931, Vollema [8] made a review of the results of 58 manurial experiments on rubber in W. Java, 16 of which were on young or slow-growing rubber and 42 on mature rubber already in tapping. In the experiments on young rubber NP and NPK gave a response in all the cases in which they were included, the effect of the individual nutrients N, P, and K being positive in some cases and negative in others. Of the experiments on mature rubber N gave in 11 cases a positive result (yield-increases of 5–25 per cent.) and in 9 produced no effect. P gave small positive results (5–10 per cent. increase) in only 2 cases and K in only 1, whilst these nutrients produced no effect in 10 and 9 cases respectively. Of the 11 positive nitrogen results only 4 gave any considerable increase (15–20 per cent.) and these were on 2 types of lateritic soil. The different forms of nitrogen (sulphate of ammonia, calcium cyanamide, and nitrate of soda) all appeared to give equivalent results.

Earlier Manurial Experiments in Malaya

In 1931 Haines and Falconer Flint [9] summarized the results of 14 Malayan experiments. About half of these experiments had been carried on for 3–4 years, but the remainder for shorter periods. The results differed greatly in the various experiments and the authors concluded that, although certain general rules emerged, it would be necessary to proceed cautiously along the line of further experimentation before commercial manuring programmes could be recommended. They noted that little correlation could be discerned between soil type and response to manuring, but that where trees of poor appearance had given yield-responses, there had been obvious vegetative improvements first.

A series of reports has also been published in Malaya [10, 11, 12] giving details of a manurial experiment on young rubber carried out by the Rubber Research Institute at their experiment station. This experiment was laid out in 1928 on land cleared from virgin jungle shortly before planting, and the trees were manured from the start. The treatments included N, NP, PK, and NPK (both inorganic and in the form of cow-dung). Although cow-dung appeared to produce some initial advantage in growth-rate, no appreciable effect had been obtained with any of the fertilizers when the last set of measurements was published and the trees were approaching maturity. It appears that in this experiment reserves in the virgin soil were quite

adequate for all practical purposes and needed no assistance from outside sources.

Grantham's Experiment on Red Soil

In his second paper [2] Grantham mentioned that even on the red soils of Sumatra after the age of 12–15 years a gradual deterioration in the trees set in, not unlike that observed on the white soils, the foliage becoming perceptibly thinner and yellower, the leaves smaller, bark-renewal poorer, and yields beginning to fall off. The main differences observed on the two types of soil are that on the red soil the process takes place more gradually, and that before the vigour of the trees is exhausted they attain a better development and a higher level of yield. Accordingly, in 1926 he put down a carefully laid-out experiment consisting of four series of treatments, each with 8 replications of $\frac{3}{4}$-acre plots arranged in chessboard fashion. The treatments consisted of annual and biennial dressings of nitrate of soda, annual dressings of sulphate of ammonia, and an unmanured control. The effect of the manures was much slower than on the white soils, and yield-increases did not become appreciable till about the third year. There was no doubt, however, that the yields on the manured plots did improve steadily. The last report of this experiment gave the figures for the sixth year [4]. The relative yields of the two series treated with annual dressings of nitrogen had by then risen by just over 30 per cent. in comparison with the control, and the series treated with nitrogen biennially by about 20 per cent. On the control plots deterioration was advancing rapidly, die-back on the smaller branches being quite common and the foliage distinctly lighter in colour. The percentage increases were much smaller than those obtained on the white soils, but, as Grantham pointed out, the initial yield-level of the controls on the red soils was considerably higher when the experiment began. Grantham mentions that in 1928 an extension was added to this experiment comparing NP manures with sulphate of ammonia. After four years phosphate had shown no additional improvement over that given by nitrogen alone, though it did appear to exert a favourable influence on the growth and appearance of the trees.

An Experiment in Ceylon

There only remains to be mentioned an experiment laid out at Peradeniya Experiment Station, Ceylon, at the end of 1929 on 9–10 year-old rubber planted on the avenue system [13, 14]. This experiment consisted of 5 randomized replications of 4 treatments (annual half and full dressings of nitrogen, annual dressings of complete inorganic fertilizer, and control). The results up to the end of the fourth year are given in a recent paper [15], but are not very conclusive. The full dressing of nitrogen and the complete fertilizer appear to have given rather better yields than the control, but the differences are slight. It should be mentioned, however, that the plots of this experiment are small (only 20 trees each) and that the conditions do not appear to be

very typical. In spite of their age the trees had not been tapped prior to the commencement of the experiment.

IV. *Description of Recent Experiments on Mature Rubber*

In order to condense the large number of new experimental results available to us, we shall describe in detail only a few typical cases as well as those having special features, and give summaries of groups of experiments on uniform plans which provide grounds for certain generalizations. The most usual response is a slow and progressive one, but there are some cases of very quick returns, as well as others which show no response at all (where plant-food is sufficient in relation to other limiting factors).

1. *An Old Nitrogen Trial*

The first case to be described is chosen because it has a longer history than most and at the same time is quite typical. The rubber was of the orchard type, growing on land which had suffered a chequered history for 7 years before planting. The trees were 14 years old at the time of the first manuring in 1927 with sulphate of ammonia at the rate of $4\frac{1}{2}$ lb. per tree. At the existing stand of trees this was equivalent to $2\frac{3}{4}$ cwt. per acre. The application was repeated yearly till 5 applications had been given and was then stopped. Improvement in the yield from the manured areas has been continuous to the present time, but the controls have deteriorated to a level of only 250 lb. per acre per annum. Expressing results as percentage comparisons, the manured area started at a disadvantage of 16 and steadily rose to an advantage of 22 at the end of the third year. Then followed two and a half years' resting, as the bark on the control areas was barely tappable. On re-opening in 1933 the comparison was over 50 per cent. in favour of the manured area and is remaining near this level, although no fertilizer has been applied since 1931. The change in appearance and development of the manured trees has afforded a most remarkable contrast with the control, although now after five years without manuring there are symptoms in the trees that the effect is beginning to diminish.

2. *Dunlop Nitrogen Trials*

The next series of trials is chosen because the large area covered allows perhaps the most reliable simple generalization yet available. The trials were started in 1930 on several of Dunlop's estates as a simple test of sulphate of ammonia on fields of rubber past their prime. Blocks were taken of anything between 8 and 16 tasks and half of each block retained as control, whilst half received 4 lb. of sulphate of ammonia per tree per annum, the recording of task-yields going on without disturbing estate routine. Fig. 1 represents a summary of the results from 20 such simple comparisons on three different estates, covering in all a total of 134 tasks, or over 500 acres. Two curves show the average yearly yields from control and manured areas, these being much influenced by the fact that high cuts (giving reduced yield) were predominant in the years 1933 and 1934. The trend of percentage improvement

due to manuring is also shown, giving equal weight to each of the 20 comparisons regardless of their individual differences in area. The average improvement in yield is 34 per cent. in the sixth year, but in the best cases the improvement has reached 75 per cent. Similarity between these results and Grantham's red soil experiment (p. 306) is very marked.

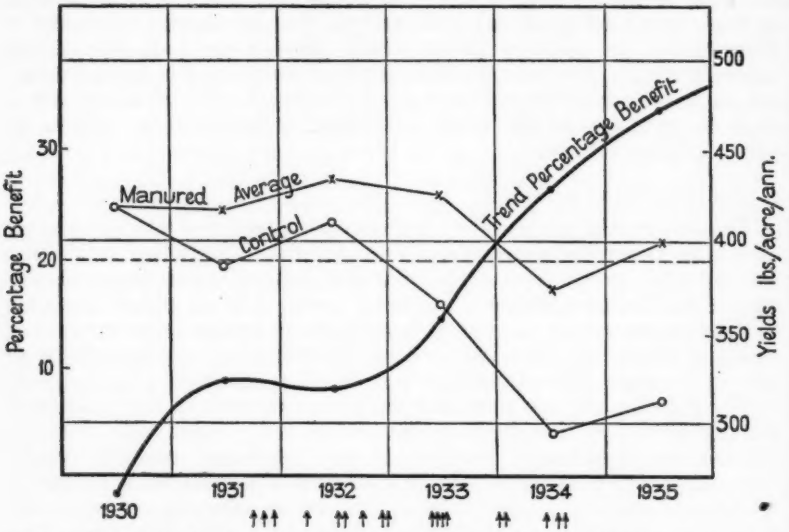

FIG. 1. Results of an extensive nitrogen trial (Dunlop's) showing in the percentage curve the two stages in which response usually occurs. Arrows show incidence of new tapping-cuts, giving reduced yields, in the different fields of the trial.

The average yield was about 350 lb. per acre per annum, and we may say that an increase of 20 per cent. of this would repay the yearly cost of the treatment (about 30*s.* per acre inclusive of labour). Drawing a cost line at 20 per cent. in the diagram we may judge the appropriate areas between this and the trend of percentage benefit and find that accumulated expenditure and return reach a balance in the seventh year, after which the extrapolated curve indicates a profit at least equal to the expenditure. The showing of other experiments is that a more conservative use of fertilizer would have given an economic balance at an earlier date. The widening difference between the yields from control and manured areas appears at first sight to be due to deterioration of the controls rather than to actual improvement of manured areas, but an analysis which was made to take into account the effect of height of cut showed an equal division of the difference, half to deterioration of controls on the one hand and half to improvement of manured areas on the other.

The curve shows two phases in the response to manuring. The main response, which we attribute to improved bark, begins to be really effective only in the fourth year, but superimposed on this is a smaller

and earlier response reaching its full in the second year and not increasing further. This we suppose to be linked with the greatly improved foliage which is noticed over the same period. Such improvement must be accompanied by improved transpiration and synthesis of those products in the tree from which latex is derived, thus giving some increase in yield through improved sap-pressure or latex-secretion, or both. It appears, however, that this particular effect quickly reaches a new equilibrium and that the fuller response in yield waits upon some slower change in the bark character. Theorizing on physiology would be out of place, but the dual character of response comes out in many cases and provokes further inquiry.

3. *I.C.I. Experiments on Mature Rubber*

The next set of results comes from the experiments under the control of Imperial Chemical Industries, Ltd. Unlike the previous experiments, in these the fertilizer was applied biennially and not annually. The general plan is a 3×3 Latin square with plots varying in size in the different experiments from 100 to 250 trees (1–3 acres) and including the following treatments: O = Control, N = Nitrogen alone (4 lb. of sulphate of ammonia per tree), and NPK = complete fertilizer (Enpekay No. 1) at a dressing calculated to give an equal quantity of nitrogen, the ratio of the other plant nutrients being, where N = 1, P_2O_5 : K_2O = 1 : $1\frac{1}{4}$.

In 1931 altogether fifteen of these manurial experiments on mature rubber were laid out on various estates in different parts of the Malay Peninsula, but of these seven have had to be rejected as unsatisfactory. Two were abandoned prematurely by the estates concerned during the world economic crisis on the ground of economy, and it has not proved possible to obtain reliable records from the five others owing to changes in the management or other causes. Of the remaining eight, one is described under Section 5 below and the results of seven are summarized in Table 2. In this table, the actual annual yield of the control is given in each case, together with the percentage relation of the two manured series to the control. The object of this method of presenting the results is to eliminate the apparent confusion caused by violent fluctuations in some of the annual yields, due either to a long resting period (No. 3, 1932–3) or to the ABC system of tapping (No. 5), and so to give a clearer picture of the effect of manuring on yield. The increases obtained in the different experiments up to the fifth year vary from about 10 to 25 per cent.

Of the seven experiments in the summary, one gave very quick response in yield (No. 10), three gave economic response in the third year, and two in the fourth or fifth year. One (No. 2) has not yet given an economic return. In this experiment the NPK treatment has caused a certain rise in yield, but it has not yet reached an economic value. In estimating the return on manuring the comparative level of the original yields in each series prior to manuring has always been taken into account.

Experiment No. 10 was laid out on poor rubber of the orchard type

TABLE 2. *Summarized Data from I.C.I. Experiments (Mature Rubber)*

Experiment No.	2				3				5				6				8				9				10		
Age (1931)	14				8				19				17				16				16				12		
Stand per acre	88				100				73				57				107				85				84		
Soil	Lateritic loam: Fairly good				Sandy laterite: Poor				Quartzite silt: Good				Friable sandy clay: Fairly good				Grey sandy loam: Fair				Lateritic loam: Poor				Quartzite loam: Very poor		
Topography	Undulating				Mainly flat				Mainly flat				Undulating				Flat				Very hilly				Flat		
History prior to planting	Cultivated				Cultivated				Cultivated				Cultivated				Cultivated				Virgin				Cultivated		
YIELD-control in lb. per acre per annum (manured series as per cent. of control)	O	N	NPK	s.e.	O	N	NPK	s.e.	O	N	NPK	s.e.	O	N	NPK	s.e.	O	N	NPK	s.e.	O	N	NPK	s.e.	O	NPK	s.e.
1931	705	105	106	..	560	93	92	..	688	103	86	6·5	503	105	99	..	608	115	105	..	500	108	109	..	454	118	2·8
1932	504	110	113	9·9	260	93	86	..	433	101	86	..	503	106	100	..	601	119	107	..	593	105	109	..	422	124	..
1933	410	102	108	..	825	105	100	1·3	362	104	82	..	496	118	113	0·7	444	125	115	..	360	108	108	..	412	133	..
1934	430	103	116	4·3	681	103	102	..	771	105	83	3·9	*Not recorded*				415	141	124	4·5	*Not recorded*				405	125	..
1935	468	107	119	..	850	104	94	..	406	112	94	1·1	379	116	108	3·9	450	128	116	..	279	134	140	3·2	324	124	2·2
ECONOMIC RESPONSE (on N treatment)	Not yet				Third year				Fifth year				Third year				Third year				Fourth–fifth year				First year		

O = Control: N = Sulphate of ammonia only, 4 lb. per tree biennially: NPK = Enpekay No. 1 (12½ per cent. N, 12½ per cent. P_2O_5, 15 per cent. K_2O), 6½ lb. per tree biennially: s.e. is the standard error of the figures in the treatment columns (which express the percentage comparison with the control).

Experiment No. 2, 1932, is five months' tapping only: rested for remaining seven months of the year.

Experiment No. 5 on 'ABC' tapping (one year's continuous tapping followed by six months' rest), causing marked fluctuation in annual yields; 1931 and 1934 are complete year's tapping; 1932, 1933 and 1935 include six months' rest.

Experiment No. 10 did not include N series, but consisted of simple trial with NPK and control (4 replications each). Though very rapid response was obtained the cost of applying a complete fertilizer is high and the return is only just economic.

Experiment No. 1 is described under section (6). Experiments Nos. 4, 7, 11, 12, 13, 14, and 15 have had to be omitted owing to premature abandonment or lack of regular records.

and gave almost immediate response, the relative yield of the manured plots increasing steadily month by month after the first manuring and then remaining on the average 25 per cent. above the control. This is the only experiment which did not include a series manured with N alone, and the increase obtained is only just sufficient to cover the cost of applying the complete fertilizer. In the other experiments, with the sole exception of No. 2, nitrogen alone has always given as good a response in yield as NPK. At a stand of 80–100 trees the cost of applying sulphate of ammonia in alternate years does not exceed 12–15*s.* per acre per annum, so that an increase of even 10 per cent. in yield may be considered profitable on average types of rubber yielding 400–500 lb. per acre.

In the majority of the experiments foliage-response was fairly rapid and in some cases became apparent during the first few months. After two or three applications the contrast in appearance between the manured plots and the control has usually become very marked, even where economic returns have not yet been obtained or are only just beginning. The denser leaf-canopy giving heavier shade, the darker colour of the foliage, and the softer, thicker, and often darker-coloured bark are most noticeable on manured areas. Measurements of bark-thickness have been made in all the above experiments and are referred to later (p. 316).

4. *Dunlop 25-Plot Experiments*

The next set of results is from the Dunlop Estates, and, providing as it does eleven cases of all kinds under one scheme of treatment, gives scope for investigating the laws governing differences in behaviour. The lay-out was designed by one of us (W. B. H.) on the assumption that nitrogen would be necessary in all cases and that the support of minerals might be of value; the possible value of an organic form of fertilizer was also tested, as most soils are deficient in humus. Each experiment includes the following five treatments in five randomized blocks, each plot providing a light task of 200 trees on alternate-day tapping: A = control; B = N, sulphate of ammonia at $5\frac{1}{2}$ lb. per tree; C = NK, sulphate of ammonia plus muriate of potash; D = NPKX, organic fertilizer (meat-meal); and E = NPK, complete inorganic fertilizer (Nitrophoska). The schedule finally worked to gave nitrogen in the following proportions B and C:D:E = 1:0·68:0·93 (with a deviation to smaller amounts in the D plots in three of the experiments).

One experiment started in 1930 and the other ten in 1931. Table 3 gives a summary of all the relevant data, all the manured plots in each experiment being averaged together, since differences between them were not significant (see Table 4) except in the one case mentioned later. Since neither the addition of minerals to nitrogen nor the use of organic fertilizer improved the results, the economic value of the response has been judged on the cost of applying nitrogen alone. Out of the 11 experiments, 4 fairly quickly gave responses which may be considered economic, 2 began to respond after 3 to 4 years, whilst 5 still fail at the fifth year to give any adequate return. Of these 5 cases, 4 were started before there was obvious need of manuring, so leaving only one case of unexplained poor response (No. 2).

TABLE 3. *Summarized Data from 25-Plot Experiments*

Experiment No.	1	2	3	4	5	6	7	8	9	10	11
Age (1931)	8	19	14	17	12	11	22	17	11	14	12
Stand per acre	100	62	100	82	78	105	71	86	85	99	100
Soil	Alluvial clay: Fairly good	Lateritic: Fairly good	Brown loam: Very good	Alluvial clay: Fairly good	White clay: Poor	Stiff clay: Fair	Stiff clay: Fair	Stiff clay: Fair	Stiff clay: Fair	Brown lateritic: Very fair	Stiff clay: Poor
Topography	Flat	Fairly hilly	Undulating	Flat	Flat	Undulating	Fairly hilly	Fairly hilly	Very hilly	Undulating	Fairly hilly
History prior to planting	Virgin	Virgin	Cultivated	Virgin	Virgin	Virgin	Virgin	Cultivated	Cultivated	Cultivated	Cultivated
YIELDS: lb. per acre per annum	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.
1930	300 321 14	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..
1931	505 549 11	475 472 8	656 693 27	595 638 21	437 442 12	620 624 ..	370 379 18	386 380 ..	352 379 19	261 340 24	331 372 15
1932	516 520 ..	555 571 ..	.. .. ..	657 676 ..	498 508 ..	597 599 ..	345 400 18	520 514 ..	359 430 40	192 375 64	{387 422 11
1933	494 520 15	500 520 ..	.. .. ..	504 563 ..	539 570 20	522 552 17	432 500 17	517 534 ..	388 460 48	215 382 38	{ .. .. ..
1934	563 606 ..	290 296 15	578 632 26	422 473 48	487 503 ..	577 578 ..	379 467 23	532 544 26	369 451 ..	253 441 44	201 373 18
1935	591 600 ..	322 349 ..	608 723 32	479 532 34	361 368 ..	548 553 ..	157 217 12	567 568 ..	400 451 ..	283 544 ..	160 322 20
ECONOMIC RESPONSE	Not yet	Not yet	Fifth year	Fifth year	Not yet	Not yet	Second year	Not yet	Second year	First year	At change-over (third year)
GROWTH: Girth-increment in inches per annum											
1931–2	O 2·55	O 0·62	O 0·60	O 0·90	O 0·64	O 1·20	O 0·35	O 0·65	O 0·45	O 0·20	O 0·10
1935–6	O 1·00	O 0·41	O 0·24	O 0·39	O 0·61	O 0·42	O 0·10	O 0·65	O 0·38	O 0·20	O 0·01
	N 1·61	N 0·74	N 0·63	N 0·55	N 1·06	N 0·79	N 0·42	N 1·00	N 0·82	N 0·62	N 0·91
	NK 1·45	NK 0·70	NK 0·72	NK 0·58	NK 1·05	NK 0·78	NK 0·20	NK 0·82	NK 0·93	NK 0·64	NK 0·91
	NPKX 1·55	NPKX 0·73	NPKX 0·61	NPKX 0·61	NPKX 1·91	NPKX 1·25	NPKX 0·41	NPKX 1·15•	NPKX 1·06•	NPKX 0·42•	NPKX 0·56
	NPK 1·56	NPK 0·88	NPK 0·61	NPK 0·61	NPK 1·48	NPK 0·98	NPK 0·43	NPK 0·89	NPK 0·96	NPK 0·65	NPK 0·98

O = Control: N = Sulphate of ammonia only, 5½ lb. per tree: NK = sulphate of ammonia, 5½ lb. per tree, and muriate of potash, 3½ lb. per tree.
NPKX = Complete organic, meat-meal ('Sterameal'—7 per cent. N: 10 per cent. P_2O_5; 5 per cent. K_2O), 11 lb. per tree (• Expts. 8, 9 and 10, 9 lb. per tree).
NPK = Complete inorganic (Nitrophoska = 16½ per cent. N; 16½ per cent. P_2O_5; 21 per cent. K_2O), 6½ lb. per tree. Ratio of amounts of nitrogen (treatment N = 1) NK : NPKX : NPK = 1 : 0·67 : 0·92.
M = Average for all manured plots, differences between treatments not being significant. s.e. is the standard error of a difference between M and O.
Sudden drops in yield are due to change-over of cut to a new panel.
Economic return reckoned for rubber at 6*d.* per lb. (with Tamil tappers on daily wages) and for treatment with sulphate of ammonia only.

Experiment No. 10 is the outstandingly successful case, and a graph of the average annual yield is shown in Fig. 2. The period happens to cover the tapping of one complete 42-in. panel. Improvement in yield was immediate, and has been progressive to the present time, the average benefit to all manured plots in the fifth year with the tapping-cut nearing the base of the tree being an increase of 92 per cent. in yield. Both in appearance and performance the manured areas have advanced from poor backward rubber with no future to a very good stand with further

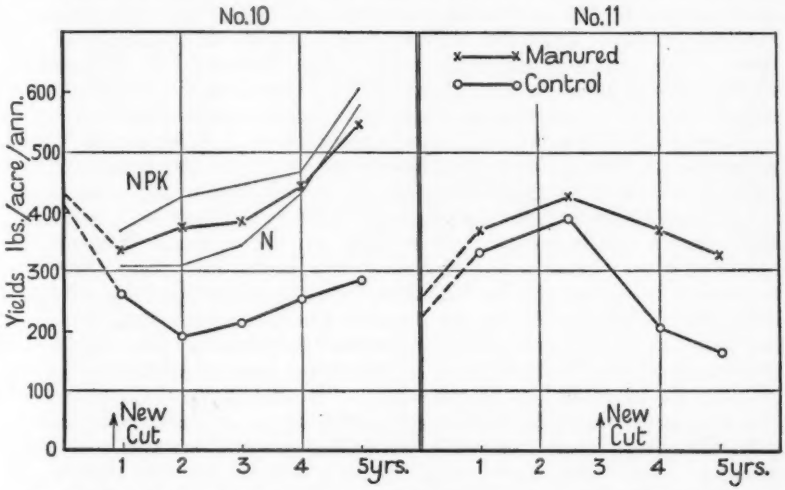

FIG. 2. Two of Dunlop's experiments. Plots manured annually. The yield-value at the beginning is a reliable estimate only. Since the height of cut repeats itself in the fifth year the yield would do so also if conditions remained unchanged. Manuring has therefore definitely advanced the yielding capacity, but the controls have deteriorated.

improvement still in store. A photometer test of ground-shade on the plots towards the end of 1935 showed eight times as much light coming through the foliage of the control trees as through the manured. The special reasons for the outstanding response in yield cannot yet be exactly defined. The land is undulating with a clay soil and laterite gravel. The soil character varies in patches from a light-coloured, stiff phase showing impeded water-circulation to a red, softer phase with much easier drainage. There is marked response on both phases, which suggests that there is a big determining factor in the trees themselves. The point of similarity with the other two cases of quick response, namely the HAPM white-soil experiment (p. 303) and No. 10 I.C.I. series (p. 309), is that the trees were young, though in great need, being in this case in their fourteenth year when manuring began. The land also had been under cultivation before planting, and the stand is of the orchard type. In respect of soil there is little similarity to the responsive white soil of Sumatra.

In order to bring out a special feature in this experiment separate curves are shown for the N and NPK treatments. It will be noticed that the plots receiving nitrogen alone were much behind the completely manured plots for the first two or three years, but that later a rapid overhauling took place. One may suppose that the trees were originally in need of minerals as well as nitrogen, but that there is a cumulative effect of sulphate of ammonia which gradually allows the extra minerals to be found. This may be a reaction in the soil, but is more likely to represent a reaction of the trees which can better exploit the soil when root-expansion and improved transpiration follow the restoration of the leaf-canopy. Thus the mineral-deficiency is not fundamental like that of nitrogen, and although in cases like this additions of minerals at first greatly assist in a quick recovery, there is obviously no need to supply them continuously as a support to nitrogen manuring.

The site of Expt. No. 11, whose results are also shown in Fig. 2, is similar to No. 10 in most obvious respects, but the events took a different course. No benefit was shown at first, but when, after nearly three years' manuring, the tapping-cut was changed over to a new panel, there was a much greater fall in yield on the controls than on the manured plots. During the first two years on the new panel there has been some tendency for the benefit to increase, although the yield itself is falling slightly owing to the peculiar position of the cut. Yield on the manured plots is now double that on the controls. The behaviour of No. 10 seems at first sight to be somewhat incongruous with that of No. 11, for whereas No. 10 gave immediate increases, the response of No. 11 was delayed and seems to show mainly as an arrest of deterioration. But deterioration can only be judged properly by comparison of yields at similar heights on successive tapping-panels, and the data in Fig. 2 are just extensive enough for such a judgement to be attempted. The period of five years just covers the length of time taken for the cut to travel down one tapping-panel, so that, if conditions had been stable, the curves would at the end of the five-year period be back at the values at which they started, i.e. the curves would exactly repeat. This enables one to say, on examining the actual levels which the curves have reached, that in both experiments the divergence between the manured and control curves can be ascribed in about equal proportions to deterioration of the unmanured rubber and to real improvement of the manured. This confirms the conclusion expressed in section 2 above.

No. 7 is a good case of gradual improvement in old and fairly well-grown rubber. Here nitrogen alone proved fully as good as other treatments even from the first, since there had been no mineral deficiency produced by earlier cropping. The benefit reached an economic level after the second year of manuring, and although the yields received a severe check in the last year, as is usual in old rubber when the tapping changes to a new high cut, the percentage benefit took a bound forward from 23 to 38 per cent. at the change-over. No. 9 gave fair response; Nos. 3 and 4 are giving a late response after being doubtful for the first 3 or 4 years.

Combining the yields for all six cases of response and comparing treatments on a percentage basis we have:

TABLE 4. *Yields. Comparison of Treatments, Responsive Cases*

Treatment	*1931*	*1932*	*1933*	*1934*	*1935*
Control . .	100	100	100	100	100
N only . .	109	119	118	137	145
NK . . .	111	123	121	139	148
NPKX (organic)	111	117	114	131	139
NPK . .	116	130	128	143	152

From this table it may safely be deduced that, for the fairly heavy dressings given to all plots, nitrogen by itself produces nearly a full effect, and that the extra cost of the other treatments would be quite unjustified commercially. The organic treatment has received one-third less nitrogen than the others (though at much greater cost), which would account for its being a little behind. We obviously need to know more about the optimum dosage before a closer or final interpretation could be attempted.

The five remaining cases of this group show so far effects in yield which are too small to be of any real value. Effects on appearance are, however, very marked in practically every case—indeed, they are so marked that an uninstructed observer would sometimes hardly credit that plots so different in appearance could produce yields so nearly the same. Future benefits therefore seem certain.

Table 3 indicates that a yield-level of about 425 lb. per acre per annum separates the lower-yielding cases which respond quickly from those higher-yielding ones which are slow. The cases of biennial treatment of Table 2, being all save one in the higher-yielding group, do not therefore compare suitably on the question of dosage with the annually treated experiments of Table 3. It seems safe to say, however, that the annual treatment is necessary where there is much leeway to be made good, but that it is certainly too heavy where the circumstances only require that deterioration be prevented. If manuring is started in time, i.e. as soon as failure in foliage is apparent, applications at long intervals will usually suffice.

5. *Effects on Girth and Bark*

The effects of manures upon girth-increment are more immediate and definite than upon yield, for growth-improvement is established in every case without exception. Since the activity of bark-renewal is in a sense complementary to girth-increment, improvement of the one may be assumed to follow the improvement of the other. Also, since girth-increase comes before yield-increase and is easier to measure accurately, it should be given close attention.

Girth-records have been kept in all the experiments described under section 4 (Dunlop), and appear to form the best means of classifying their behaviour. Growth-rates at the time of the first manuring varied from 2·2 in. per annum, on the youngest experiment just in tapping, to

a negligible figure of say 0·1 in. per annum on the most starved and stunted site (No. 11). All four cases which gave ready yield-response were growing at a rate of less than 0·5 in. per annum when manuring began and all other cases above this rate. Thus the standard of 0·5 in. per annum could have been used at the beginning to give a correct forecast of those cases which would quickly respond in yield. Further, the two experiments which gave delayed response had fallen below the same standard (on the controls) when the economic return began to show. In the three cases where response is most obviously lacking the untreated plots are still growing at a rate of 0·6 in. per annum or over. Again we may note that all manured plots (with one exception and that the oldest rubber) have been raised above the half-inch standard by the treatment. It therefore appears that a standard growth-rate of about ½ in. per annum forms, for this representative set of experiments, a natural limit below which deterioration is so marked that manuring is urgently called for, but above which the bark is still maintained in a fairly satisfactory condition. Such a criterion is easily applied (without the uncertainties or ambiguities which affect measures of yield, bark-thickness, and so on), and appears to have great promise in assisting diagnosis and treatment. With fuller knowledge the standard suggested could be adjusted for age of trees, and perhaps also for different soil or climatic regions. An analysis of the cases given in section 2 afforded full support to this conclusion, that the growth-rate is a good indicator for judging the expectation of response.

The relationships of the girth-increments for the different treatments in the experiments described under section 4 were as follows (average all experiments):

TABLE 5. *Girth-increase*

Control	100
N only	207
NK	199
Organic	233
NPK	227

In most cases the plots settled down quickly to a new growth-rate corresponding to the improved nutrition. Since the organic treatment contained much less nitrogen than the other treatments, and yet heads the list, it would appear to have some special value for growth-stimulation, though nothing exceptional is shown yet for yield-increase. Examination discloses that this special feature is confined to the cases of most rapid general growth.

Bark-renewal is found to follow suit with girth-increments, though here the technique of measurement is subject to a much greater error. The following result (Table 6) is given by combining the bark-measurements of 6 experiments (I.C.I) described under section 3 and receiving biennial treatments. The average period of manuring was 3¼ years and the average period of renewal 2¼ years, i.e. the renewal-period had been in all cases within the period of manuring. Plot-figures were averages of about 100 trees, and 3,400 trees altogether are represented in the

analysis. The significance on Fisher's z test was just over the 1 per cent. point.

TABLE 6

	Bark-thickness (in mm.)	*Differences* (due to manure)
O . .	6·53	..
N . .	7·68	1·15
NPK . .	7·72	1·19
Standard error	0·26	0·37

Bark-renewal is improved on the average by over 17 per cent., although in individual cases the figure rose to nearly 40 per cent. Both the above tables strongly confirm the conclusion that nitrogen is the only element of outstanding importance in fully mature rubber.[1]

6. *Cases of Lack of Response*

Although five of the experiments described in the preceding group of cases (4) have not yet given economic response, the improvement in appearance shows that manuring has benefited the trees and gives promise for the future. There are cases, however, where good foliage without manuring suggests a nutritional sufficiency, and the following typical one shows that further addition of nutrients does not in such circumstances force on yields. This experiment, one of the I.C.I. series, was laid out in 1931 on tall well-grown trees, planted in 1910, and situated on a stiff but well-drained coastal clay soil. The lay-out was a 4×4 Latin square of 1½-acre plots (125 trees each) and included the following treatments: O-control, PK-superphosphate plus sulphate of potash, NPK-complete fertilizer (Enpekay No. 1), and NPKX-complete fertilizer together with traces of the minor elements, copper, zinc, and manganese. The fertilizers were applied biennially at rates calculated to supply 0·81 lb. P_2O_5 and 0·98 lb. K_2O per tree to all the manured series, and 0·81 lb. N to the two which received complete fertilizer.

[1] Measurements of bark on the Dunlop 25-plot experiments were not complete at the time of writing. The figures available all show a very high level of significance and give the following percentage comparisons:

Bark-thickness Dunlop 25-plot Experiments (two to five years' renewal)

Treatment	A *Control*	B N	C NK	D NPKX	E NPK
Experiment No. 1 .	8·54 mm. = 100	105	101	102	103
„ No. 2 .	6·45 mm. = 100	111	110	120	119
„ No. 5 .	6·42 mm. = 100	110	107	118	117
„ No. 8 .	6·01 mm. = 100	114	112	119	113
„ No. 9 .	5·49 mm. = 100	124	120	130	126
„ No. 10 .	5·55 mm. = 100	118	116	122	119

The organic treatment D has given the thickest bark in most cases, in spite of the smaller amount of nitrogen applied, and the observation is general that the bark is softest on these plots. The main conclusion seems to be that, although the bark-thickness has increased along with the other improvements, this measurement does not afford a specially good index for estimating yield-responses.

When the experiment began the trees were yielding 550–600 lb. of dry rubber per acre, and throughout its course there has been little sign of any decline in yield. In this case the trees appear to have been able to find all the nutrients they required in the soil, so that manuring has produced little or no improvement. These flat, coastal clay soils are known to be comparatively rich, and, where the rubber is unsatisfactory, suffer more from lack of drainage or poor soil-texture than from deficiency in nutrient elements. Normally they grow excellent stands of rubber with heavy dark-green foliage and satisfactory yields, and attempts to improve them by manuring have not been successful. Cases are known where these soils have been replanted after carrying a stand of rubber for upwards of 30–35 years, following the previous cultivation of sugar or other crops, and the young trees have made growth equal to that on newly opened virgin jungle soils without any fertilizers being applied.

7. *Special Cases of Mineral Deficiency*

As already mentioned, the great majority of experiments on mature rubber show that there is generally little need to apply phosphoric acid and potash in addition to nitrogen. Special cases are known, however, where applications of minerals have produced a marked response after nitrogen had apparently failed to do so. Unfortunately, accurate experimental data are not forthcoming, but these cases are of two kinds. The first is recorded from tracts of sandy soil containing much black organic matter and showing a gritty white surface, a good example of which occurs in Central Perak. This soil is particularly deficient in potash, resulting in stunted growth of the trees and in die-back of the branches, associated with a peculiar yellowing or browning of the leaves, which appears to be a form of rim-blight. One of the earliest of the I.C.I. experiments was put down on this type of soil and included a series manured with sulphate of potash, but it was abandoned by the estate concerned during the period of economic depression before any records had been taken. In spite of this, visual effects on the trees were so great that extensive manuring with potash was undertaken later. Although no accurate estimate can be made of the effect on yield, there appears to be no doubt that on neighbouring estates considerable areas have since been resuscitated by rectifying the potash deficiency in this particular type of soil.

The second kind of case is met mainly in the south of the peninsula on certain areas where previous cropping, heavy erosion, and long exposure have so exhausted the soil that rubber is hardly able to grow at all. The trees here are of the small orchard type and remain permanently stunted. On these areas deficiency in phosphate appears to be the main factor limiting growth, and striking results, first in growth and later in yield, have been shown to follow the application of phosphate fertilizers. Until experimental results are available it is not possible to enlarge further on these special cases, but they are worth noting as exceptions to the general rule that applications of minerals are not required on mature rubber.

8. *Other Problems Related to Manuring*

Cultivation with undergrowth.—In order to maintain more natural and sheltered soil conditions on rubber estates, the practice of allowing controlled undergrowth is steadily growing in favour. Natural forms are permitted owing to the difficulties in introducing legumes beneath mature rubber which are as yet not generally surmounted. There are at the present time no experimental results capable of unambiguous interpretation, but this paper would be incomplete without some reference to the bearing of manuring on such practices. The great point to be emphasized is that the two methods are not antagonistic but in many ways complementary.

Competition between cover and trees will always occur, and good management consists in keeping the balance on the side of the trees. Disastrous consequence can follow if undesirable forms of undergrowth get out of hand. Now the one thing required for natural control is overhead shade, and nothing is more certain than the recovery of leaf under manuring: a bag of sulphate of ammonia is the equivalent of new leaves and more shade. In that way the fertilizer will partly pay for itself in saving costs on weed-control. It is found that sulphate of ammonia is taken up much more readily by the more vigorous roots of the trees than by the undergrowth, and it has proved quite possible to make the application without first weeding the ground, though such preparation of patches for application may usually be advisable.

The natural effect of the undergrowth is to improve the nitrogen status (or activity) of the soil, but the process is always slow. This slow effect may be sufficient in good rubber, but will in most cases be quite inadequate to meet the very pressing needs for recovery. Manuring, on the other hand, can raise the nitrogen supplies immediately, and to any desired amount. It is, therefore, a necessary adjunct to rapid improvement, even if the so-called 'forestry' methods should prove adequate by themselves after a new balance at a higher level of soil activity has been attained.

Oidium leaf-disease.—Increasing anxiety in recent years regarding the ill effects of *Oidium* would seem to be very largely due to the increasing weakness of the trees, if the districts chiefly concerned are any criterion. Apart from the question of greater susceptibility due to slower development of new leaves after wintering, the strain of renewal after a second defoliation from disease is a very severe one on trees whose poor reserves are already exhausted. Manuring enables these reserves to be restored and maintained, so that although it cannot strictly be regarded as curative, it strongly counteracts and alleviates the bad effects of *Oidium*, and should be regarded in most cases as a necessary and obvious support to any other measures. Sulphate of ammonia enables the new leaves to be produced easily and their development through the vulnerable stages to be quicker.

Soil acidity.—Rubber soils are naturally acid, having a pH value usually around 4·6 to 4·8, but sometimes going as low as 3·0 or even lower. It is probable that, under the heavy leaching which is normal,

residual effects of the fertilizers used are not important. Grantham's experiment indicates that prolonged manuring with nitrate of soda is not harmful. In one case our results led to the suspicion that prolonged use of calcium cyanamide (which would build up lime in the soil) is not desirable. We are of opinion that any acidity resulting from continued use of sulphate of ammonia will be advantageous rather than detrimental.

V. *Young Rubber and Replanting*

Young rubber offers a much simpler problem than the old, because if growth-response is obtained the economic benefit of early maturity is very great and yields may be left to look after themselves. Here, as in older rubber, manures may be ineffective if conditions are good. This is sufficiently proved by the R.R.I. experiment [12] on a virgin soil, in which manuring had no effects on growth-rate up to maturity on a seedling area which made 4 to 6 in. girth per year without assistance. Later tapping-figures may show more result than girth-increase has done. But if conditions are poor, as in replanted sites, the benefit of manures can be in no doubt. One such experiment was started in 1935 on six-year-old replanted rubber (old rubber cleared 1925 and followed by four years' abandonment, then replanted mixed seedlings and buddings, 1929, without manures) and gave the following result after the first year of manuring:

TABLE 7. *Young Replanted Rubber*

	Girth-increment (in. per annum)	
	Buddings	*Seedlings*
O (Control)	1·56	2·50
N (2 lb. sulphate of ammonia per tree) . .	1·66	4·16
NK (sulphate of ammonia plus sulphate of potash)	2·40	3·80
NPK (3 lb. per tree Enpekay No. 1) . .	2·66	4·52
Standard error	0·15	

Here the chief feature is the small effect of nitrogen on the buddings unless backed by potash, though this does not show with the seedlings.

Another case in which phosphate was the mineral required is given in Table 8. These are the first year's results of an experiment on young

TABLE 8. *Young Rubber, Buddings*

	Girth-increment (in. per annum)	*Differences due to manuring*
O (control)	3·39	..
N (sulphate of ammonia only) . .	3·30	−0·09
NP (Nicifos B)	4·26	+0·87
NPK (Enpekay No. 1)	4·30	+0·91
NPKX ('Sterameal' young-rubber mixture) .	4·18	+0·79
Standard error	0·16	0·23

rubber, planted in 1927–8 on old tapioca land and budded in 1931, but not manured till 1935 (lay-out four randomized blocks). Here the lack of result from nitrogen without phosphate is very striking and gives a good example of the possibility of making mistakes without proper guidance. The effect of phosphate alone is not tested, but a number of other results suggest that it may be by far the most important element in the combinations. The organic treatment had rather less phosphate than the other treatments (though the same amount of nitrogen), which accounts for its slightly lower result.

Young trees seem much more susceptible to mineral deficiencies than older ones, and phosphate or potash may take the place of first importance, although the assistance of nitrogen may be valuable. Many cases are found to require only one mineral element, so that economy can be effected if such knowledge is gained. It is easily obtained by simple experiment during the early rounds of manuring replantings (when complete fertilizer can in general be given, for amounts and costs are small), and then, if need be, the element not required can be stopped.

The following results (Table 9) were obtained in a replanting experiment on budded rubber (Clone BD.5) on a rather open loam soil (first cleared 1905). Manuring started in March 1933 at about 18 months old, and the figures given are the mean increases in girth during the third completed year of manuring. The lay-out is a 4×4 Latin square (O, P, K, PK), with each plot split for added nitrogen. The effect of PK is fully significant and that of K fairly so, but the effects of N and of P are not significant.

TABLE 9. *Annual Girth-increment Young Budded Rubber (BD.5), Inches*

Treatment	*Without N*	*With N*	*Difference due to N*	*Average*	*Difference over control*
O . .	2·70	2·63	−0·07	2·67	..
P . .	2·71	2·92	+0·21	2·82	0·15
K . .	3·01	2·89	−0·12	2·95	0·28
PK . .	3·35	3·57	+0·22	3·46	0·79
Standard error	0·21	0·21	0·30	0·15	0·21

Fisher's z test showed a value just better than the 5 per cent. point for the whole experiment. Beneficial interaction between P and K is indicated with fair significance. As regards less significant suggestions, it may be noticed that nitrogen has no effect when alone or with potash, but that in the presence of phosphate it appears to have some small effect. This interaction has appeared in other cases. Briefly, the experiment shows potash to be the most important element when used singly, but the beneficial interactions between all elements when applied together makes a complete fertilizer the best choice. The NPK treatment has produced 25 per cent. increase in the rate of growth during the whole period. If that benefit were simply maintained (and there are signs that it is accelerating) the PK plots would come to maturity more

than 1 year, and the NPK plots nearly 2 years, before the controls, which would in itself repay the cost of manures. The yearly increment of 3½ in. per annum for the NPK plots, though fairly low, may be reckoned quite good for the Clone BD.5, which branches late and puts on girth only slowly at first. This experiment again demonstrates the importance of minerals for young rubber. The insignificant effect of N may be reckoned rather exceptional, but it usually takes a place of second importance at that stage. In other cases on heavier soils one may expect to find P more prominent in its results, and in some such cases K has been found to be of no importance.

Such results are quite general and will probably be much improved upon when manuring is started at first planting. The only limiting factor to successful replanting (omitting root-disease) is whether the soil fails to afford a sufficiently well-drained and aerated situation for root-growth. Rubber does not do well on very heavy soils in which air- and water-movement are slow, even under proper drainage systems, and it cannot be expected that fertilizers will overcome such limitations. If natural drainage is adequate the early stages of growth can certainly be supported by artificial application of plant-food (as witness the successful growth of plants in water-cultures), the while humus recovery and soil activity are forwarded by means of cultivating covers. Enough has been said to show that replanting without including a manurial scheme would be highly hazardous. It should also be emphasized that manuring in the earliest stages is important, or the plants may take on a set sluggishness from which it is difficult to rouse them.

VI. *Recapitulation*

Taking all the experience covered directly or indirectly in the present paper we seem justified now in attempting to make generalizations to serve as guidance in practice. Cases where yield-levels have been immediately raised are comparatively rare, and seem to be associated with rubber young enough to have retained some vigour, but backward on account of the soil being exhausted by previous cultivation. These 'orchard-type' cases may justify a first dressing of complete fertilizer, but afterwards nitrogen alone should be given. In older rubber, where deterioration has occurred at some time late in the planting history, further deterioration may with certainty be arrested by manuring with sulphate of ammonia, and a degree of restoration will probably follow, particularly where age is not too advanced. The improvements occur in two stages, the first being an increase of the order 10 per cent. during the immediate phase of improving foliage, and the second a much larger increase beginning in the fourth or fifth year, as benefit to the bark becomes effective. Relatively high yield-levels are not generally raised by manuring. The magnitude of the yield-increases therefore depends largely upon the degree of restoration required, and they will usually soon become economic if the yield-level of the stand has fallen below 400 lb. per acre per annum. Frequency of application should be measured in terms of degree of starvation, and if a beginning is made as soon as deterioration shows in foliage, then applications with two-,

three-, or even four-year intervals may suffice to maintain good foliage, from which good bark-renewal and stable yield may be assumed to follow.

If deterioration is fairly advanced the immediate response may be enough to justify economically a yearly application. As a standard for judging this, we arrive tentatively at a growth rate of half-an-inch girth-increment per year. If growth is much better than this, then deterioration of yield is probably not due for some years and a calculable return is not in sight. Manuring would, however, seem justified at suitable intervals so soon as need is shown, as a measure of insurance against loss, which is none the less real for being distant in time. When growth is below the standard named, need is urgent and recovery is likely to be quick enough to justify yearly expenditure and to give a calculable return in increased yields.

The experiments examined prove fully that nitrogen is the fundamental manurial need, and they have not brought to light any advantage as to yield commensurate with extra cost from the addition of minerals to nitrogen on old rubber, nor from the use of organic forms. Any departure, therefore, from the rule of using sulphate of ammonia alone in old rubber would seem to require strong justification as a special case. Such cases are likely to occur on a special type of potash-deficient soil, and sometimes on soils long cleared before planting. In younger areas where growth is of prime importance, whether to hasten maturity or to pull stunted rubber out of premature senility, the addition of minerals to nitrogen is usually required as a first stage, and the possibility that organic fertilizers may sometimes have a special advantage to justify in part their extra cost is not entirely ruled out.

Where replanting is feasible, it is in the long run an alternative to be preferred to rejuvenation of old stands, because of the higher-yielding material available for new stands. Manuring of the young rubber must then be considered quite essential for success. Complete fertilizers are best, for nitrogen without minerals is ineffective in these cases, and simple experiments can be run concurrently with the early stages of planting to decide which element, if any, may be dispensed with. The design of such an experiment should cover interactions as well as direct effects, all combinations being tried, namely N, P, K, NP, NK, PK, and NPK. If there are no outstanding problems concerning drainage, hardpan, or root-disease, then the success of replanting should be assured by the use of fertilizers and a proper policy of humus-conservation and soil improvement by the cultivation of covers.

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UNMANURED MANURED

TYPICAL EFFECT OF MANURING ON FOLIAGE

This experiment was laid down on poor mature rubber which was carrying very thin foliage (see unmanured plot). Sulphate of ammonia was applied in 1931 and again in 1933, and the photograph (taken in 1935) shows the marked improvement which has taken place in the foliage as a result of manuring

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THE ROOT-SYSTEM OF THE SUGAR-CANE

Pt. III. THE EARLY DEVELOPMENT OF THE ROOT-SYSTEM OF SUGAR-CANE IN MAURITIUS

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WITH PLATE 17

Introduction.—In the second paper of this series (this *J.*, 1936, **4**, 208) the mature root-systems of the most important sugar-cane types were described, and the root-systems of several other varieties, important commercially or for breeding, have been described in detail in Bulletin No. 6 of the Sugar-cane Research Station, Mauritius. It is important to know exactly how these mature root-systems are built up, especially those of the commercial varieties, for these varieties are manured and cultivated when the root-system is very immature. Data on the quantitative development of the root-system of virgin, or plant, canes of White Tanna have been presented in Bulletin No. 7 of this Station.

The present paper contains qualitative observations on the distribution and extent of the root-system at various times up to six months from the date of planting, the varieties used being White Tanna, BH. 10 (12), and POJ. 2878. The root-systems were examined, by the 'block' method, when the plants were 2, 3, 5, and 6 months old, and were subsequently reconstructed in specially made frames. Climatic conditions were very favourable during the whole period of growth.

The Root-Systems at Two Months (*Plate 17, Figs. 1, 2*)

Some of the relevant data on the two-month-old root-systems are summarized in Table 1.

TABLE 1

	White Tanna	*BH. 10 (12)*	*POJ. 2878*
Distribution, length, &c.	Uniform. Sett-roots mainly inactive. Longest roots 33 in. Aver. point of termination 20–25 in. from stool. Max. depth 24 in., mean depth 10–12 in.	Slightly asymmetrical, shallow. A few sett-roots active. Mainly superficial roots; longest 39 in. Aver. pt. of termination 24 in. Max. depth 18 in., mean depth 12 in.	Mostly active sett-roots, longest 30 in. Longest superficial roots 12 in.; mean length 3–4 in. Max. depth of buttress-roots 18 in.
No. of roots:			
Total . .	175	138	..
Superficial .	155	102	37
Buttress . .	20	34	2
Buttress on primary shoots .	2	2	..
Buttress on secondary shoots	18	32	..

Thus there is a marked difference in the rate of development of the root-system in the three varieties, POJ. 2878 being outstandingly slow. A very interesting feature which appears to have been established for all three varieties is that the proportion of buttress-roots to superficial roots on the primary shoots is very much lower than on the secondary shoots. The thicker superficial roots of White Tanna often attained a diameter of 5 mm. and branched only towards their terminations. In BH. 10 (12) the slight asymmetry in distribution of roots was correlated with the position of the shoots, root-formation being more vigorous on the side of the cutting where most buds had developed. The root-system of BH. 10 (12) was more shallow, but had a slightly greater spread than that of White Tanna at 2 months; there were still many active sett-roots, indicating a less advanced state of development, as compared with White Tanna. The root-system of POJ. 2878 at 2 months was more like that of the other two varieties at 1 month; it still consisted, in the main, of sett-roots, and was only in the earliest stages of formation.

The Root-Systems at Three Months (*Plate 17, Figs. 3, 4, 5*)

The data on the 3-month-old root-systems are summarized in Table 2.

TABLE 2

	White Tanna	*BH. 10 (12)*	*POJ. 2878*
Distribution, length, &c.	Increase in number, spread and branching of both types. Superficial system localized in a zone 4–16 in. deep; max. length 42 in. Buttress-system, lateral spread 24 in., max. depth 34 in., mean depth 20–24 in.	Increase over 2-month system less marked than in White Tanna. Distribution more uniform. Number of superficial roots less than in White Tanna; max. length 50 in. Buttress-system, lateral spread 24 in., max. depth 30 in., mean depth 24 in.	Marked development between 2 and 3 months. Sett-roots mostly inactive. Superficial roots, max. length 34 in., mean spread 24 in., depth 14 in. Buttress-roots well developed but pass downwards almost vertically; max. depth 27 in., mean depth 14 in.
No. of roots:			
Superficial .	275	202	216
Buttress . .	26	41	34
Buttress on primary shoots .	..	..	11
Buttress on secondary shoots	..	..	23
Sett-roots .	very few	few	..

The progress of root-growth between the second and third month was quite marked in the three varieties, but more in White Tanna and POJ. 2878 than in BH. 10 (12). In all three varieties there were very few roots in the first 3 in. of soil. The mean spread of the superficial system is such that most of the interline is fairly intimately explored by the roots at 3 months. The development of buttress-roots is more marked in BH. 10 (12) than in the other varieties. The root-system

as a whole, however, is best developed in White Tanna at this stage. There was very active root-growth in POJ. 2878 between the second and third months; the system at three months showed much more change from that at two months than in the other two varieties.

The Root-Systems at Five Months

Table 3 summarizes the main features of the 5-month-old root-systems.

TABLE 3

	White Tanna	*BH. 10 (12)*	*POJ. 2878*
Distribution, length, &c.	Marked development between 3 and 5 months. Longest superficial roots 60 in., mean length 36–42 in.; number much increased. Development of buttress-system less marked; max. depth 36 in., mean depth 30 in.	Spread not increased between 3 and 5 months. Few superficial roots 42-48 in.; mean length 24–30 in.; mostly thinner than in White Tanna, but buttress-system more extensive; depth 54 in., mean depth 30–36 in.	Marked increase in length between 3 and 5 months. Superficial roots only in first 12 in.; max. length 30 in. Buttress-system increased, but lateral spread still about 12 in.; longest roots 48 in., mean depth 24–30 in.

Appreciable root-growth, more particularly in length, occurred between the third and fifth months, also increased branching of roots already present, as well as an increase in the number of roots.

Development in White Tanna had occurred mainly in the superficial system, whereas in BH. 10 (12) and POJ. 2878 buttress-root development had been active, tending towards a deeper-seated system.

The Root-Systems at Six Months

Data on the six-month-old systems are given in Table 4.

TABLE 4

White Tanna	*BH. 10 (12)*	*POJ. 2878*
Marked increase in no. of roots; spread also greater. Superficial roots: max. length 72 in., mean length 48–54 in.; abundant down to 18 in.; increased proportion of thick roots.	Superficial roots, considerable increase in no.; max. length 54 in., mean length 36 in. Many penetrated slightly obliquely.	Many new roots, but no increased spread. Superficial roots, mean length 36 in.; penetrated to 18 in.
Buttress-system increased; max. depth 48 in., mean depth 36 in., lateral spread 48 in. No deep roots other than buttress.	Buttress-roots, no increase. A few roots of the wiry-rope type present, forming a poorly developed rope penetrating to 60 in.	Buttress-system more vigorous; max. depth 48 in., mean depth 36–42 in.; lateral spread increased to 24 in. A few deep roots of black, wiry type; one 'embryonic' rope-system penetrating to 60 in.

Development between the fifth and the sixth months was marked, and consisted mainly in the protrusion of a considerable number of new roots, and to a smaller extent in increased growth and branching of roots previously present.

Small rope-systems were observed for the first time at 6 months of age, though the number and degree of organization of these rope-systems were considerably lower than are found in mature root-systems.

Summary of Root-Development in White Tanna, BH. 10 (12) and POJ. 2878

Certain features in the early development of the root-system are common to all three varieties. Thus, root-growth is initiated by the cutting or sett giving rise to the temporary sett-roots, root-functions being afterwards taken over by the shoot-roots, which form the permanent root-system of sugar-cane. Up to 6 months the shoot-roots consist almost exclusively of the two classes of roots which have been described as superficial roots and buttress-roots. The primary shoots (those formed directly from the sett) bear superficial roots almost exclusively. When they bear buttress-roots also, these originate at a later date than the superficial roots. On the other hand, the secondary shoots (i.e. those originating from the primary shoots), and shoots of a higher order, bear a large number of buttress-roots, and these almost always protrude before the superficial roots, which may also be borne on these shoots.

An appreciable time may elapse before the primary shoots form roots, but roots occur on secondary shoots and on those of a higher order at a relatively early age. It is quite common to see young secondary shoots, still below ground-level, and less than 3 in. long, with no unfolded leaves, bearing several buttress-roots, often up to 18 in. in length. The buttress-roots are thus generally the first to protrude on the secondary shoots and those of a higher order, superficial roots being formed later. Primary shoots never have many buttress-roots, and it seems that the greater vigour of growth of secondary and other shoots of higher order, as compared with the primary shoots, may be due to the former being equipped with an adequate buttress-system in addition to superficial roots. The buttress-roots have been shown to be of great importance in the water-economy of the sugar-cane (Bull. No. 5, Sugar-cane Res. Stat., Mauritius).

There are, however, marked differences in the rate of growth of the root-system in the three varieties, the order of merit being White Tanna, BH. 10 (12), POJ. 2878. Under the favourable conditions occurring during the whole of the growing-period, White Tanna had an almost fully developed root-system at 6 months of age, those of the other two varieties at the same age being still immature.

The mature root-system of B.H. 10 (12) had a much greater depth than the 6-month-old system, but that of POJ. 2878 was altogether more extensive as regards spread, number of roots, and depth to which the roots penetrated than the 6-month-old system. There is therefore a

marked difference in the rate of development of the root-system in the three varieties, POJ. 2878 being outstandingly slow; this is in accordance with the behaviour of the three varieties in the field.

The Effect of Subsoiling on Root-Development

Planters have recently taken much interest in subsoiling, which is carried out with an implement capable of breaking up the subsoil *in situ*. It is not yet known whether such treatment causes an increase in yield under normal conditions, but there is evidence that it may be beneficial in the control of *Phytalus Smithi*, as the operation results in the death of some larvae. Preliminary experiments have suggested that the depth of root-growth might be favourably affected by subsoiling, and the work herein described was designed to investigate this problem. Two varieties were used, BH. 10 (12) and White Tanna, and the root-systems were examined in detail by the 'block' method at 3 months of age. Subsoiling was done by carefully removing the top-soil and then breaking up the subsoil to a depth of about 3 ft., the top-soil being then replaced in its original position. Controls were examined at the same time.

White Tanna.—At 3 months of age there was no apparent difference in the aerial portion of the stools; there was, however, a remarkable difference in the root-systems, the most striking being in the depth and density of the roots. Even in the surface-soil, root-development was more vigorous in the treated plots. Superficial roots were longer, more numerous and more branched; this was probably due to the loosening of the surface-soil as a result of its removal and subsequent replacement, which suggests that even a cultivation of the top-soil has a very beneficial effect on root-growth in this region, the absorbing surface being considerably increased. The distinction between thick and thin superficial roots observed in the control stools was not so marked in the treated stools. The mean spread of the superficial roots in the control stools was 4½ to 5 ft., whereas in the treated stools it was 6 ft.

As would be expected, subsoiling had most effect on the buttress-system. The remarkable fact emerged that the nature of the buttress-roots was fundamentally affected by the treatment; they were so modified as to appear almost identical with superficial roots, except that they were lighter in colour. They did not show any of the distortions that are usually typical of these roots; they were cylindrical and ribbed to a slight extent; they branched profusely, giving rise not to the thick, flattened secondaries which they usually bear, but to thin secondaries bearing profuse fibrous rootlets along their entire length. Buttress-roots were more numerous in the treated stools, and their lateral spread extended to 4 ft., with no sharp delimitation. Some buttress-roots had penetrated to 3½ ft., and most of them terminated at a depth of about 3 ft. There were, therefore, at this stage of development only a few roots that penetrated beyond the subsoiled region. In those few which had done so, that portion which had penetrated the undisturbed subsoil showed the normal features of buttress-roots. It appears, therefore,

that the typical morphological characteristics of buttress-roots are not inherent in these roots, but are caused by the nature of the subsoil in which they are located.

BH. 10 (12).—The root-system of BH. 10 (12) was also markedly affected by subsoiling, the depth and number of roots increasing considerably. Branching was also more prolific than in the untreated stools, though not nearly so profuse as in White Tanna. As shown above, branch roots are normally more sparse in BH. 10 (12) than in White Tanna.

Buttress-roots also assumed the features of superficial roots in the treated plot of BH. 10 (12); and there was an even greater difference in the distribution of roots between the treated and untreated stools of BH. 10 (12) than was found in White Tanna. The root-system of the treated stools had a mean spread of 5½ ft., with some superficial roots 4½ ft. long, and a mean depth of 3½ ft., a few penetrating to 4 ft. Plate 17 (Figs. 6 and 7) shows the root-systems of White Tanna and BH. 10 (12), respectively, under subsoiled conditions; they should be compared with Figs. 3 and 4.

To summarize: subsoiling had a very marked effect on the root-system of the two varieties investigated: the treated stools had a greater spread and depth, and the roots were more numerous and more profusely branched. The main differences between buttress-roots and superficial roots disappeared as a result of the treatment, the former assuming the features of the latter.

Discussion

Quantitative and qualitative studies on the development of the young sugar-cane root-system are very important for elucidating problems connected with the cultivation of this crop, and for determining the most efficient cultural methods. They also shed light on the most likely behaviour of the young plants under conditions of drought or attack by *Phytalus*. The spread of the root-system, even in very young canes, shows that when the canes are planted in the ordinary way with 4½–5 ft. between the rows and 2½ ft. between the stools in the row, the interline is fairly intimately explored by the roots, though there are comparatively few roots in the first 3-in.-layer of soil.

It would appear, therefore, that the application of fertilizer in rather concentrated masses in the middle of the clump is not in accordance with the distribution of the absorbing roots, but rather that the fertilizer should be distributed as uniformly as possible over the field, and turned in to a depth of between 3 and 6 in.; it would then stand a good chance of being absorbed. After a time the region of the root nearest the stool becomes conducting only; it is not actively engaged in absorption, though it may still bear some root-hairs, and fertilizer applied in this region is available only to young unbranched roots passing through it. Only in well-advanced canes, whose leaves have effectively closed over the interline, are roots to be found in the very superficial soil layer (down to 2–3 in.), and the broadcasting of fertilizer all over the interline

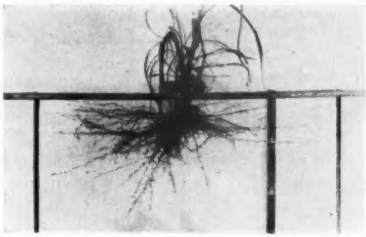

FIG. 1. White Tanna, 2 mths. old

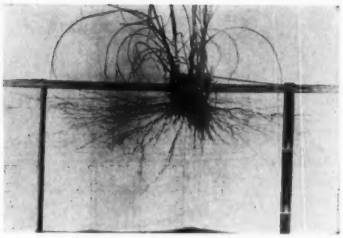

FIG. 2. B.H. 10(12), 2 mths. old

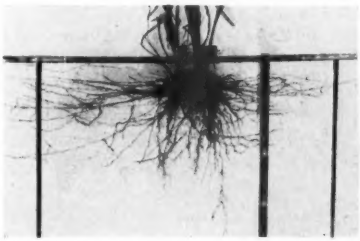

FIG. 3. White Tanna, 3 mths. old

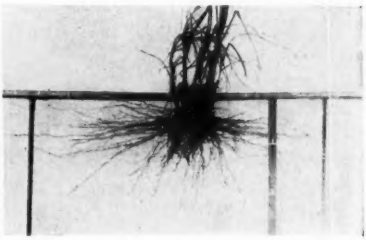

FIG. 4. B.H. 10(12), 3 mths. old

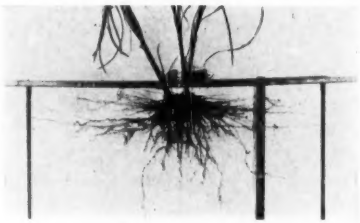

FIG. 5. POJ. 2878, 3 mths. old

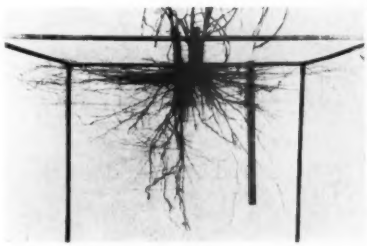

FIG. 6. White Tanna, 3 mths. old (subsoiled)

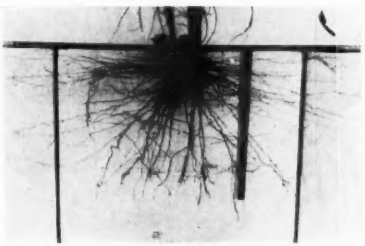

FIG. 7. B.H. 10(12), 3 mths. old (subsoiled)

A SELECTION FROM THE ROOT-SYSTEMS EXAMINED
(Scale in feet)

will therefore not be fully effective unless it is at the same time turned in to the requisite depth.

There is little doubt that application of fertilizer should be made for the benefit of the buttress-roots also, since these form an increasingly important part of the root-system. It is obviously more difficult to apply fertilizer to this class of roots. The operation could only be undertaken profitably before planting the virgin, or plant, crop, by working the fertilizer into the soil at the bottom of the hole. Field experiments to test the efficiency of the new methods of fertilizer applications suggested as a result of root-studies are now in progress, preliminary tests having indicated a superiority of the modified methods over the method hitherto in vogue.

The distribution of roots under subsoiled conditions, and the improvement even of the superficial system in cultivated top-soil, point to the desirability of such intensive cultivation. Even if it so happens that under good growing-conditions no marked increase in yield results (a question still to be solved), it is difficult to imagine that no beneficial effects would occur under abnormal conditions. The root-system produced as a result of subsoiling, being superior in depth, spread, and number of roots, to that of the untreated plants, must result in considerable benefit to the plant under conditions of drought, or high winds accompanying cyclones, or heavy *Phytalus* infestation. The buttress-roots have already been shown to play an important part in the water-relations of sugar-cane, and a buttress-system superior in depth, branching, and number of roots must be of considerable benefit under the dry conditions that are so common in Mauritius. Again, *Phytalus* larvae have been shown to occur mainly in the first foot or so of soil, and an adequate system below this depth should contribute greatly towards increased resistance to the larvae. This, of course, is in addition to the direct killing of larvae caused by the subsoiling operation.

The observations tend to point out that cultivation and 'devidage' (the cutting of trenches near the stools, which are afterwards filled with farmyard manure and covered up, a practice common in Mauritius) should be carried out as early as possible. If the operation is delayed until the plants are 3 to 4 months old, considerable damage to the root-system must result, which, if followed by a drought, might occasion a serious set-back in growth.

Determinations of the total absorbing-surface of the root-system of the three varieties described in this paper have also been completed; they will be discussed in a later publication.

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PAMPAS GRASS (*Cortaderia Selloana* (Schult) Aschers and Graben): A NEW SUPPLEMENTARY FODDER FOR RUMINANTS IN NEW ZEALAND

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WITH PLATES 18, 19

Introduction.—Although the South American pampas grass has become established in many parts of the world as an ornamental plant, the possibility that this quick-growing giant tussock may provide valuable fodder does not seem to have been considered until quite recently, when a New Zealand farmer[1] observed that dairy cattle thrive if allowed to graze this coarse fodder as a winter supplement. The Hauraki Plains district, where the experiments were initiated, comprises the reclaimed estuarial land of the flood plains of the Piako and Waihou rivers, Hauraki Gulf, Auckland. Here the use of pampas grass as a mid-winter and mid-summer supplement has become firmly established with the result that the possible utility of this new fodder is being investigated in other parts of the North Island of New Zealand.

In the Hauraki Plains pampas grass does not naturally regenerate from seed, probably because both sexes are not represented, all stocks being asexually derived from the handsomer female plants. The extensive reclamation of estuarial lands in the Whangarei Harbour, North Auckland, has, however, become in places a nursery of wild pampas seedlings capable of supplying millions of young plants and seeds at a very low cost to farmers.

Pampas grass (*Cortaderia Selloana*[2]) is the well-known South American plume grass, which, according to Lindley and Moore [1], was introduced into Europe in 1843 through seeds from Buenos Aires sent to the Glasnevin Botanical Gardens, Ireland. It is now thoroughly domiciled in Europe and found in almost every large garden in Britain. Hitherto, in Europe and Australia, it has been cultivated entirely for the ornamental effect of the tall, dense, silvery plumes of the female plants; the male plants bear plumes significantly less ornamental, as shown by the two groups of wild plants in the illustration (Plate 18, Fig. 1).

Palatability of Pampas to Cattle and Sheep

It is stated on good authority that pampas grass in South America is regarded as a pest, and is rooted out and burnt wherever it is desired to utilize land for stock-farming; and that it is never eaten by stock in Argentina. Because a plant is little valued in its original habitat is no proof that it will not have a use in another climate and soil, for instance,

[1] Mr. McClean obtained with what is described by breeders as 'a very ordinary herd', a premium of ½d. per lb. for his produce, which was graded 'First Finest Quality' and in yield per acre exceeded that of his neighbours.

[2] The authors are indebted to the Director of Kew Gardens, Sir Arthur Hill, for the correct botanical name of this species.

Pinus radiata (*insignis*) (Monterey pine) and *Cupressus macrocarpa* (Monterey cypress) were not regarded as of much economic use in California, yet when grown in South Africa, Australia, and New Zealand these species provide quick-growing timber and are valued shelter-belts and fences.

Von Mueller [2], an eminent Australian botanist, refers to the pampas grass of Uruguay, Paraguay, and La Plata as an industrial plant because, as was shown by him, paper can be made from its leaves. The Australian soil and climate, like that of South America, may be generally too dry for the completely successful use of pampas grass as a fodder, but W. L. Mardon of Sylvania, Sydney, N.S.W., a farmer of beef cattle, writes that he has always noticed that stock were fond of pampas grass at certain periods. He finds that on fair-quality drained swamp, on fair-quality black, red, or grey soils (on sandstone strata) pampas flourishes like a weed. He states that the sustaining powers of pampas grass are equal, if not superior, to those of most other herbage, and it is beyond dispute that stock relish it and graze it greedily, maintaining virile health.

Over sixty years ago experiments made with pampas grass in the moist North Island of New Zealand by Sir George Grey at Kawau Island, and by Dr. S. M. Curl [3] in the Manawatu district, suggested to them that this coarse grass had been neglected as a fodder plant. Dr. Curl, as early as 1876, recorded that pampas grows to a height of 10 ft., but if within the reach of stock it is kept low, for cattle are particularly fond of its rather coarse leaves, which contain a large amount of nutriment, and grow through both winter and summer, cold having little effect. As young leaves appear, all cattle and sheep will greedily eat them, leaving more delicate herbage.

In New Zealand pampas grass has been long regarded as a suitable shelter-belt plant, particularly in Taranaki, where some form of protection from the ocean winds blowing into the Taranaki Bight is essential in order to obtain the best results from farm stock, especially pigs.

As an ornamental garden plant, pampas was evidently introduced very early into New Zealand, presumably as seed, because in the days of sailing ships plants did not travel well, and both sexes are now widely distributed. In some localities these occur together, and the seedlings spread in waste spaces. There is no record of pampas spreading into well-grazed pasture, since stock will eat out and kill any stray plants. The seed is very small: some gathered from Whangarei averaging 1,800,000 seeds to the pound. It is firmly enclosed by the glumes, so that severe treatment is required to set it free. Commercial 'seed' is therefore bulky and 'fluffy'.[1]

Pampas is to be seen growing as an ornamental plant or as a shelter-hedge in gardens and along the fences of paddocks in practically every part of New Zealand. Nearly everywhere the plants are all female, having been derived from the subdivision of a single plant, the female plant being preferred on account of its larger and more handsome

[1] It is possible to clean seed by vigorous centrifuging, so detaching the seed from the surrounding chaffy scales (the glume and palea), but there is evidence that the viability of such cleaned seed decreases rapidly.

plumes. In some localities (e.g. in parts of Otago and Southland), however, the male plants only are to be seen.

On the stop-banks of the harbour-reclamation works at Whangarei, where stock are practically excluded, thousands of seedling pampas in all stages of growth are to be found. Several counts of areas of flowering seedlings chosen at random in this locality showed an approximately equal number of male and female plants. Some variation occurs, notably in the colour of the panicles, which in some plants is red and in others yellow. By selection from these seedlings different varieties could doubtless be produced, but such variation cannot be expected among plants asexually propagated, as by means of root-cuttings.

Farmers have observed from time to time that cattle grazed with avidity these pampas windbreaks in various North Island stations, but this observation was not followed up and merely resulted in the strengthening of the fences guarding the pampas plantations. Where the pampas can attain sufficient size before being grazed by cattle, there is evidence that fencing is unnecessary, the canes being so thickly disposed and the plants so high (up to 12 ft.) that cattle merely eat the external leaves [4] (Plate 18, Fig. 2).

Despite these numerous observations of cattle grazing pampas grass, the first recorded instance of systematic utilization of this new forage, so far as the authors are aware, is due to Mr. Alec McLean, a farmer who had recently settled on reclaimed salt-marsh land at Waitakaruru, Hauraki Plains, Auckland. This pioneer, noting that comparative analytical data for New Zealand plume grass or toe toe (*Arundo conspicua*) and pampas grass had been published [5] reported to one of us (B. C. A.) in July 1932 that for several years he had been using young pampas grass successfully as a winter fodder for cattle. He had gradually increased his plantations of pampas by subdividing the clumps and planting 6 ft. apart, i.e. approximately a thousand plants to the acre. At the time of writing he had 9 acres under pampas for grazing, and was wintering his herd for the second year on pampas grass as a supplementary fodder. No other supplementary fodder was used, but the stock had a run-off of 48 acres on good cattle pasture. McClean claimed that with the aid of pampas grass he could carry on his farm of 200 acres (including 30–40 acres in the rough state) 200 head of cattle the whole year round. The practice in the district is to use hay as a winter supplement, but McClean found that his stock refused to eat hay when they could get pampas, therefore he abandoned hay-making and now relies wholly on pampas as a supplement. With this mild climate (mean temperature 57°, Lat. 37.25 S., rainfall 45 in., well distributed) and rich soil[1] derived from organic matter and sea-mud, the growth of pasture is practically continuous throughout the year. The illustration (Plate 18, Fig. 3) shows that the water-table is remarkably near the surface. The result of feeding the cattle on pampas was to improve their condition, and to make the health of the whole herd remarkably good. McClean assured inquirers that the yield of butter-fat was increased as soon as the herd was put on to pampas, and at once

[1] See analyses of soil at end.

diminished if taken off that supplement. This experience was repeated in other years. His method of feeding is to allow the cattle to graze the pampas in breaks, in winter, with the aid of a movable fence, a method the cattle themselves prefer to having it cut and carted to them. Mr. McClean has modified the original method and now feeds the pampas grass to his herd twice a year instead of once, namely at the two low grass-production periods, midwinter and midsummer, so that pampas grass may become a supplementary fodder available at any time of year. This is a particularly valuable quality for a forage plant in this country of variable seasons. Experiments, including weighing the crop, suggest that if two cuts are made a year as much as 50 tons per acre of green matter may be grown at Hauraki Plains.

The publication in October 1932 of an account of McClean's experiments [4] aroused great interest in the Waikato and adjacent districts, and the discoverer was asked both for information and plants for experimental plantations. These plants were supplied at 30*s*. per 100 subdivisions of the clump, a subdivision consisting of a portion of the stem (preferably one that has not borne flowers) and root. Thus an acre requiring 1,000 plants would cost £15 for plants alone. The senior author (B. C. A.) remembering that he had seen pampas growing wild and regenerating well in the Whangarei estuary (Plate 19, Fig. 7), arranged with the Secretary and Engineer of the Harbour Board, Mr. W. M. Fraser, to utilize unemployed labour to collect seedling pampas plants for sale to farmers. This work, supervised by a skilled nurseryman, has proved very successful in establishing pampas plantations, which by this method are of better quality and much cheaper and easier to establish than by root-subdivision from other clumps, and the mortality of the seedlings is lower than that of root-subdivisions, which suffer great losses in droughts to which seedlings of the right size are highly resistant. The seedlings are baled and carefully packed for transport by railway or boat at 30*s*. per 1,000, and already about 100,000 plants have been distributed by this method.

Although pampas was an admitted success at Hauraki Plains, where both soil conditions and climate are excellent for crop production, it does not follow that the same success will occur in other places where conditions are less favourable. The present year's work suggests that every pampas plant is palatable to cattle if the leaf is not too old; that the plant grows readily on all soils, if sufficiently deep and moist for the roots to obtain the large amount of water required for such a quick-growing, tall graminaceous plant. It apparently flourishes in all climates throughout the Dominion, and has even been reported growing well in the arid district of inland Otago (Kurow) with a rainfall of 20 in. and a severely cold winter with much frost.

Other Farmers' Experiments and Experience

The grazing experiments made in 1935 prove that pampas grass will grow successfully from subdivisions on a poor pumice soil with a deep pumice subsoil (in the Rotorua district), and that under these conditions it is attractive to well-fed calves. It has also proved attractive to stock

on a poor, drained bog-land containing many stumps (Ruakuhia Swamp, near Hamilton), where no other supplementary fodder-plant could be grown.

Mr. George Short, of Dargaville, although he has never grown pampas grass for fodder alone, has used it as a dual-purpose plant—shelter and winter stock-feed—for the past 22 years in various Auckland stations, first at Aka Aka, Waiuku, and latterly in North Wairoa district. All stock are fond of it and will break down good fences to obtain it. He has grown it on drain-banks, in paddocks, and on 'poor gum-land hills', where it thrives. It would be a great asset on exposed farms near the coast, where other shelter does not thrive. Mr. Short's photos of pampas-grass hedges five years old show how it is possible to utilize these hedges without fencing for both shelter and stock-food, if the pampas grass is allowed to grow for a few years until too dense to be eaten out entirely (Plate 18, Fig. 2).

Mr. R. G. Cranwell, of Tuikaramea Road, Frankton Junction, planted ¾ acre with pampas cuttings in the Ruakuhia Swamp, in which no other supplementary fodder could be grown, owing to the submerged stumps and other subsoil conditions. These were grazed off in the winter of 1935. The cattle ate the pampas greedily, and afterwards, when excluded from the plantation, endeavoured to get in again.

Mr. F. R. Seddon, Puketaha, seven miles from Hamilton, on the deep part of the Eureka Swamp, had planted four acres fenced into three strips. Two of these were grazed down last winter (1935), the middle strip being left. The results were satisfactory and are interesting as showing that, when grazed in winter, plants grow again so quickly that by the following autumn their leaf-growth nearly catches up that of young established ungrazed plants which were planted at the same time; the ungrazed plants developing flower-heads which reduces the development of leaf (Plate 18, Fig. 4).

The Ruakura Farm of Instruction, Hamilton, established several plots of pampas plants, derived from different sources. The plot from root-cuttings showed a high mortality, but the plants grown from Whangarei seedlings had practically all 'taken' and showed quite as much leaf-growth as the surviving plants from the cuttings, and, in addition, a far greater amount of stooling throughout the seedling plot. Mr. Rodda, the Manager, was quite convinced that the seedling method was the better way of establishing a plantation.

Mr. Grahame J. W. Harvey, Taupiri, has planted three acres from root-cuttings which will be fed off this winter (1936). This dairy farmer is a skilled plant-propagator, and as he is experimenting with Hauraki cuttings, Whangarei seedlings, and seedlings derived from English purchased seed, valuable results can be expected from his farm (Plate 19, Fig. 5).

Mr. Joe B. Simpson, from long farming experience in Taranaki, states that pampas grass (1) gives good shelter for young tethered calves, (2) provides ideal thatch, (3) is a good rough winter-food, (4) is easy to grow and provides an enormous amount of food, and (5) will improve rough parts of the farm and check growth of noxious weeds.

Major R. A. Wilson informs the authors that on his Himatangi (Foxton) sand-dune property wild pampas grass is eaten down every winter by cattle. The use of pampas grass as a new plant-staple for fixed dunes opens up fresh possibilities for farmers on the dunes. Himatangi appears to be the most southern locality where pampas grass is regenerating naturally.

Four or five of the leading types of soil in the Auckland province have, therefore, been proved to be successful sites for pampas plantations; one of them extremely rich in plant-food, the others extremely poor; the climates being fairly uniform but the soils differing in texture and composition, only one feature being common to all, viz. the good water-supply in the soil available for deep-rooted plants.

Estuarial reclamations would seem to be particularly suitable for pampas plantations, but these differ in mineral plant-food content; Whangarei drained salt marsh being extremely poor and Hauraki estuaries very rich, yet pampas grass flourishes equally in both and is palatable to stock in both; indeed, in some areas at Whangarei the pampas subjected to uncontrolled continuous grazing by cattle has been eaten out and destroyed.

There seems, therefore, to be every prospect of this new fodder-plant becoming a permanent feature of North Island dairy farms, where the soil and subsoil, being fairly deep, allow free descent of pampas roots to the moister subsoil. In the Hauraki Plains the roots have been traced to a depth of 8 ft. The Auckland province is well supplied with water, the annual rainfall on the low levels being generally from 50 to 60 in., falling on 150 to 175 days, whereas in the Hawkes Bay province, the driest area in the North Island, the rainfall is only 35 to 45 in., falling on 125 to 155 days. This area suffers from occasional droughts. It will be interesting to compare the growth of pampas in Hawkes Bay with that on the moister soil of the Auckland provincial district. A number of Hawkes Bay farmers obtained pampas plants from the Hauraki Plains district by subdivision of clumps. Unfortunately, these were planted just before the droughty summer of 1934–5, with the result that almost all of them failed. A similar result attended the trials of an experienced farmer in the Manawatu district under droughty conditions. It is probable that, had seedlings been used instead of subdivisions, the experience would have been much more favourable, as seedling-plants in the Wellington City district, which suffered from the same drought, experienced no mortality.

Although young pampas plants or cuttings are peculiarly susceptible to drought, when once established this new fodder-plant is drought-resistant—another valuable character. In the very dry summer of 1934–5 production of butter-fat in the Hauraki Plains received a severe check; many farm herds yielded only half the usual quantity, and farmers were hard pressed to provide sufficient feed for the cows. Ensilage, saved for the winter, and turnip crops, although only half-grown, were fed on most farms. In spite of the shortage of pasture Mr. McClean enjoyed almost a record season, and the butter-fat production dropped only a few points below his normal average for

January. This happy position he attributed solely to the pampas grass, which he fed regularly, and of which he had sufficient reserve for winter food. The pampas did not appear to suffer in growth or succulence from the drought.

P. W. Smallfield, Fields Superintendent, Department of Agriculture, Auckland, writes recently: 'I visited Mr. A. McClean's farm at Waitakaruru, and watched the dairy herd grazing off a break of pampas grass. Mr. McClean has for a number of years been experimenting with pampas grass as a supplementary stock-food, and recently the usefulness of this plant for general feeding has received wide attention. Some quite useful plantations have already been established on some of the poor peat areas of the Waikato, and there is no doubt that the plant has possibilities. No one could watch the cows on Mr. McClean's farm quietly grazing the pampas plants without being impressed with their potentialities—an actual living fodder for winter feeding.'

That pampas will flourish in the driest Hawkes Bay district, if the requisite cultural conditions and proper method of obtaining the plants are used, is proved by the experience of a farmer at Waipawa, Mr. J. J. Carter, who had exceptionally good results in establishing a batch of seedlings, which, unfortunately, arrived in a very dry state from Whangarei in October. He had, however, the good fortune to plant them in a year which was exceptionally wet, and on well-tilled land between rows of Chou moulier crop. Seen in December 1935 (midsummer in New Zealand) by the junior author (R. E. R. G.) the majority of the plants showed signs of growth, mostly confined to a single leaf appearing from one shoot. Seen again in mid-April 1936 the pampas had made splendid progress, individual plants being 4–6 ft. high and each having more than a dozen shoots. The growth made here was better than any observed in the milder Waikato district, except possibly in one instance. Some seedlings which were apparently quite dead when received, but had been given special treatment in a garden, responded to the better soil conditions of the garden and much surpassed those grown in the field, showing in April growth over 6 ft. long, some having stooled to about 12 in. across, and having a score or more shoots.

This farmer is convinced that, provided seedlings are planted out when received in the place that they are to occupy permanently, which should be well prepared beforehand, seedling pampas responds exceptionally well to good tillage, water-supply, and weeding. He also considers that the plants must be well fenced from stock, as when some sheep were put into the Chou moulier, a splendid crop, they broke into the pampas and ate some plants, neglecting the associated growth of clover, grass, and weeds.

This farmer's experience of the phenomenal growth of seedling pampas has been borne out by the senior author in his garden in Karori, Wellington, 200 miles south of Hawkes Bay and 600 ft. above sea-level, on a windy hill-side, but the ground had been well trenched. Twenty seedlings from Whangarei were planted closely in a line, and when a year old the first cut had to be made because the plants were shading other vegetable crops adjacent. The first cut was made on December 24,

1935, the weight being 25 lb., and the second cut was made on March 11, 1936, the weight being 23 lb.—a total of 48 lb., green weight, for the 20 seedlings. By April 12, 1936, the plants had grown another 15 in. high. Pampas evidently benefits greatly by planting in deeply tilled soil even though air and soil temperatures are low.

Chemical Investigation

In this investigation an attempt has been made to compare the composition of the pampas grass with that of certain well-known forage grasses, and to correlate, if possible, the feeding-value of this grass with the analytical data given below [7, 8]. The analyses of the pampas grass were made on samples taken from the Hauraki Plains. Sample No. 1 was representative of plants that had been fired six to seven months before cutting; sample No. 2 comprised the growth from two plants (110 lb.) during a period of about one year. A detailed account of the chemistry of the carbohydrates of these grasses is not of immediate interest and will be published elsewhere.

Although much information on the mineral-content and composition of the fats and proteins in the various forage grasses is available, the systematic treatment of cell-wall constituents, or structural carbohydrates, and the sugars has been practically neglected.

In Table 1 the chemical composition of pampas grass is compared with that of well-known forage grasses. Special attention has been given to the structural carbohydrates which, besides constituting the bulk of the dry matter in a grass, serve to discriminate between the various species.

It has been customary to group the cell-wall constituents under the term 'crude fibre' and to attribute to this fraction an energy value in the nutrition of ruminants equivalent to that of an equal weight of starch, on the ground that it is broken down in the rumen by bacteria into readily assimilable glucose. Such empirical treatment of the food-value of crude fibre, consisting as it does of a heterogeneous mixture of cellulose, hemicellulose (pentosans, hexosans), and encrusting materials, such as lignin, has not met with complete approval. It is likely, for instance, that the constituents of the crude fibre vary individually in their availability to the animal. The experiments of Furth and Engel (1931), and of Stone and Jones (1892), quoted by Mangold [11], show that the hemicelluloses, like the cellulose, are readily digested by ruminants. In contrast with starch, however, these two constituents are both made available, not by enzymic action, but by bacteria in the rumen ([12] and Schieblich, 1932, quoted in [11]). It is generally accepted that lignin is either not readily available or completely indigestible [11], but according to Woodman and Stewart [13] the digestibility of cellulose is not entirely dependent on the degree of lignification or the lignin-content of the crude fibre, since, for instance, in grass the decrease in digestibility with age is associated with a relatively small increase in lignin-content. The crude fibre constitutes the essential material of the cell-membranes, and the contents of the plant-cells can be utilized only if the cell-wall material is digestible or readily ruptured. It is apparent,

TABLE 1. *The Composition of Grasses*[1]

Species	*Ash*	*Reducing substances (as glucose)*	*Reducing substances after hydrolysis (as glucose)*	*Total pectin (as Ca pectate)*	*Total hemicellulose*	*Cross and Bevan cellulose*	*Lime (CaO)*	*Phosphorus pentoxide (P_2O_5)*	*Protein (N×6·25)*
Cocksfoot (*Dactylis glomerata*)	8·16	3·54	5·51	1·97	18·31	33·20	0·49	0·74	13·99
Meadow-fescue (*Festuca pratensis*)	7·93	1·25	6·25	1·60	18·47	24·07	0·60	0·48	10·63
Chewings fescue (*Festuca rubra*)	8·32	1·01	4·70	0·90	20·70	21·38	0·59	0·51	13·56
Crested dogstail (*Cynosurus cristatus*)	9·08	3·67	13·10	1·02	16·30	23·25	0·32	0·52	10·13
Pampas grass (*Cortaderia Selloana*):									
Sample No. 1	10·55	2·62	3·69	0·86	19·15	40·33	0·47	0·44	9·87
Sample No. 2:									
Leaf portion	8·44	1·73	4·04	1·06	21·44	40·50	0·22	0·24	8·49
Basal portion	7·26	2·60	4·96	1·54	23·51	37·32	0·15	0·22	5·43
Italian rye-grass (*Lolium italicum*)	10·10	2·87	9·05	1·04	17·60	23·95	..	..	..
Timothy (*Phleum pratense*)	8·18	2·25	6·87	1·54	17·22	20·83	0·39	0·53	12·14

[1] With the exception of the pampas grass, the figures for ash, reducing substances, pectin, hemicellulose, and cellulose were taken from Buston [9]; for lime, phosphate, and protein, from the unpublished work of Shorland and McIntosh on the experimental plots of the Department of Agriculture at Kaharoa. All the results are expressed as a percentage of the material dried at 100° C.

Note by R. J. McIlroy: For comparison with grasses analysed by Buston [9] the total hemicellulose in pampas grass samples 1 and 2 was estimated by his micro-method, which involves treatment of the grass with 50 per cent. alcohol containing 1 per cent. sodium hydroxide to remove 'ligno-saccharide' prior to extracting the hemicellulose with 4 per cent. sodium hydroxide.

Recently Norman [10] has shown that this pre-treatment removes hemicellulose as well as lignin. Accordingly, the previous treatment was omitted, the crude hemicellulose obtained being corrected for lignin, estimated by hydrolysis with 72 per cent. sulphuric acid. By this method sample 1 yielded 24·43 per cent. total hemicellulose in the dry material.

Crude hemicellulose	27·13 per cent.	
Lignin in hemicellulose	2·70 ,,	
Therefore total hemicellulose	24·43 ,,	(mean of three determinations)

Loss in alcoholic-alkali treatment 24·43–19·15 = 5·28 per cent.

therefore, that from the nutritional point of view alone further systematic examination of the cell-wall carbohydrates is needed.

Regarding the structural carbohydrates Table 1 shows that the chief difference between the pampas grass and the common forage grasses lies in the higher percentage of cellulose (37–41 per cent. as compared with 21–33 per cent.). This relatively high percentage of cellulose, together with the large yield of green material (estimated at 50 tons per acre [4]), suggests its use for paper-manufacture. The esparto grass of Spain and Algeria, used for paper-pulp, contains about 45 per cent. of cellulose. Comparative figures for the lignin in the common forage grasses are not available. The determinations of this substance in the pampas grass gave from 16·5 to 18·5 per cent., as compared with 17·9 per cent. given by Norman and Jenkins [14] for grass. Less sugar appears to be present in the pampas than in the other grasses given in the table. As compared with the standards given by Orr [15] for good forage grass, the pampas grass, including the whole of the above-ground portion, or considering the green leaf and basal portions separately, is deficient in lime, phosphate, and protein (CaO, 0·15–0·47 per cent., as compared with 1·10 per cent.; P_2O_5, 0·22–0·44 per cent., as compared with 0·77 per cent.; and protein, 5·43–10·67 per cent., as compared with 18·3 per cent.). When, however, it is considered that pampas grass is intended only as a supplementary fodder, it will be appreciated that the high proportion of carbohydrates is useful in balancing pastures high in protein, whilst the evident palatability and high yield of dry matter (more than 25 per cent.) must not be overlooked. Turnips, for example, although richer in protein (14·4 per cent.), are poor in phosphate (0·14 per cent. P_2O_5), and contain only about 10 per cent. of dry matter, whilst hay from mixed grasses contains 8·75 per cent. protein and 0·38 per cent. P_2O_5 [16].

To account for the evident ease with which such a fibrous plant as pampas grass is digested by ruminants, it has been suggested that as lignin occurs in intimate association with cellulose, these constituting together the greater part of the fibre or cell-wall, the lignin, being itself indigestible, protects the other plant constituents against the action of the ruminant's digestive juices. Where, however, as in pampas, the same amount of lignin is spread over a much larger amount of cellulose, the protective action of the lignin will be diminished and the plant more easily digested.

Summary

Pampas grass (*Cortaderia Selloana*) provides under certain conditions an excellent supplementary fodder for cattle, the coarse leaves being easily grazed. The New Zealand plume grass or toe toe (*Arundo conspicua*), although similar in appearance to pampas grass, is not read ly eaten by stock, unless chaffed, on account of the relatively great tensile strength of the leaves.

Pampas grass flourishes on a wide range of soils in New Zealand, being particularly suitable for reclaimed salt marsh. Although plantations suitable for grazing may be established from cuttings, the ideal

method is to plant from seedlings which are spaced 6 ft. apart (1,000 plants per acre). The seedlings, at first in seed-pans, are transferred after selection to a frame or a suitable seed-bed. When they are 6 months old they are ready to plant in the field. The planting should be done in the spring when there is no longer any danger of frost. The plantation should not be grazed until the end of the second year and then only intermittently in breaks, the animals having a run of pasture.

Comparative analytical data show pampas grass to be low in phosphate, lime, and protein, as compared with the common forage grasses. The high proportion of carbohydrate, however, is useful in balancing the high protein-content of young pasture grass.

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FIG. 1. Pampas grass in flower showing male (right) and female (left) flowers at Whangarei Harbour reclamation

FIG. 2. Pampas hedge 5 years old. Dargaville, Northern Wairoa

FIG. 3. Pampas break, McClean's Hauraki Plains, showing eaten out break of pampas and mounds of dead leaves uneaten, also shallow water table

FIG. 4. Two breaks of pampas, Hamilton. Grazed on right of fence during winter, ungrazed on left

FIG. 5. Pampas plantation in flower and ready to be grazed off for the first time, Taupiri

FIG. 6. An acre of pampas in bloom, Taupiri

FIG. 7. Wild seedling pampas on reclaimed salt mud flat, Whangarei

ANALYSES OF SOIL AT WAITAKARURU, HAURAKI PLAINS, AUCKLAND (cf. pages 334–5)

(*a*) *Mechanical Analyses*

Results are percentages on air-dried soil.

Soil	*Analysis of 'Fine Earth' passing 2-mm. sieve*									*Stones and gravel*	
	Fine gravel	*Coarse sand*	*Fine sand*	*Silt*	*Fine silt*	*Clay*	*Moisture and loss on ignition*		*Loss by solution*		
Loam	7·9	17·5	1·3	7·8	18·3	12·7	2·9	33·1	1·5	2·5*	Top
Clay	0·5	1·9	1·0	8·5	34·5	39·2	2·6	12·5	1·3	tr.*	Sub.

* Pumice and organic matter.

(*b*) *Chemical Analyses*

Results, except*, are percentages on soil dried at 100° C.

Locality	*Volatile matter*			*Total nitrogen*	*1% citric-acid extract, Dyer's method, Hall's modification ('Available plant-food')*			
	**On air-drying*	**At 100° C.*	*On ignition*		*Lime* CaO	*Magnesia* MgO	*Potash* K_2O	*Phosphoric acid* P_2O_5
Top. McClean, Waitakaruru, unmanured. Peaty	31·0	2·9	34·2	0·808	0·063	0·127	0·018	0·048
Sub.	32·9	2·6	12·9	0·275	0·054	0·154	0·025	0·099

Locality	*Hydrochloric-acid extract ('Total plant-food')*				*Lime-requirement* % $CaCO_3$		pH
	Lime CaO	*Magnesia* MgO	*Potash* K_2O	*Phosphoric acid* P_2O_5	*On air-dried soil*	*On soil dried at 100° C.*	
Top. McClean, Waitakaruru, unmanured. Peaty	0·20	0·54	0·36	0·23	1·10	1·13	4·8
Sub.	0·27	1·12	0·51	0·26	0·51	0·52	5·0

INVESTIGATIONS ON BLACK-ARM DISEASE OF COTTON UNDER FIELD CONDITIONS

I. THE RELATION OF THE INCIDENCE AND SPREAD OF BLACK-ARM DISEASE OF COTTON TO CULTURAL CONDITIONS AND RAINFALL IN THE ANGLO-EGYPTIAN SUDAN

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Introduction

IN the following account, which deals with studies of Black Arm, a disease (due to *Pseudomonas malvacearum* E.F.S.) of cotton as it occurs in the Sudan,[1] there must, of necessity, be repeated references to the mode of cultivation practised. A short account of the latter and of the local conditions is therefore desirable.

The principal Sakel-growing[2] area of the Sudan is that irrigated tract called the Gezira, about 100 miles long and 30 miles broad, between the Blue and the White Niles, with its most northerly point about 35 miles south of Khartoum, and held by the Sudan Plantations Syndicate as a concession from the Sudan Government. For administrative purposes this irrigated area is divided into areas called 'Blocks', which are in charge of a Senior or 'Block' Inspector, assisted by one or more Junior Inspectors.

The system of irrigation and the lay-out of the cotton-land may be briefly outlined as follows. From a minor canal is led a channel (called an *Abu Ishrin*), which irrigates an area called a 'Number', 90 acres in extent. This 'Number' is divided into 9 tenancies of 10 acres, each of which is called a *Howasha*, and is irrigated by a minor channel called an *Abu Sitta* leading from the Abu Ishrin. Each howasha is 280 metres long by 150 metres broad, and is divided for watering purposes into 16 *Angaias*, each division being parallel to the shortest side of the howasha: the lay-out diagram (p. 345) indicates these divisions.

Though the tenant is the cultivator of each howasha, the cultural operations are under the control of the Inspector in whose block the howasha lies. The cotton is normally sown about the beginning of August, i.e. about the middle of the rainy season of the Central Sudan, the sowing being made on ridges 80 cm. apart which run parallel to the longest side of the howasha. In each ridge the seed is sown in holes about 30 cm. apart, each hole containing about 8–10 seeds; about 3 weeks later the cotton seedlings are thinned to 3 plants per hole.

The crop-rotation of this area is such that the *previous* season's cotton-land very often lies immediately adjacent to the cotton-land of

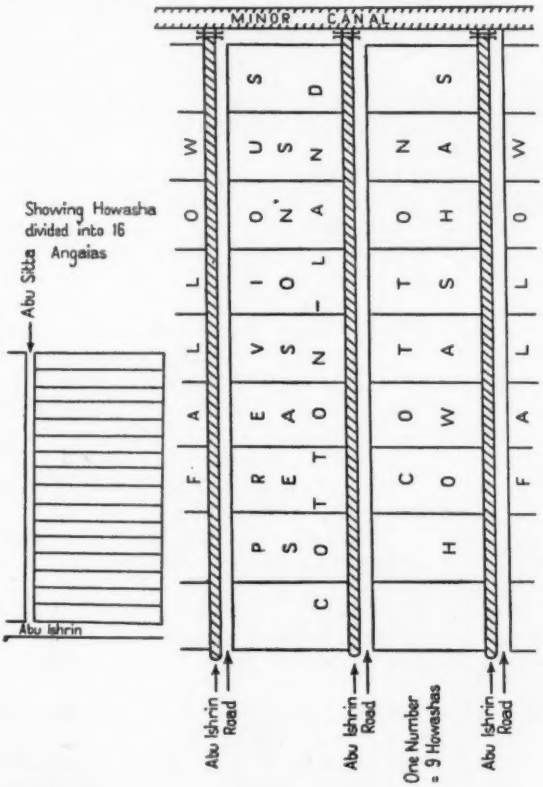
[1] For brevity the word 'Sudan' will be used for 'Anglo-Egyptian Sudan'.

[2] Sakel (a contraction of 'Sakellarides') is the variety of Egyptian cotton grown in the Gezira.

the coming season; this rotation is illustrated in the lay-out diagram below.

In the study of Black-Arm disease it was felt that the laboratory investigations in progress could be very usefully supplemented by observations on cotton plants grown on a field scale under the cultural and

Unit Lay-out of Cotton-land in the Gezira



climatic conditions prevailing in the Gezira. It was hoped that information of the limiting factors of the spread and perpetuation of the disease in the field would be obtained, and would form the basis for a method of control. It was therefore decided that the cotton of certain howashas scattered through the Gezira area should be kept under close observation for the incidence and spread of the disease. These observations were made under the supervision of the author, with headquarters at the Gezira Research Farm, Wad Medani, and this paper embodies the results obtained during the seasons 1932–3 and 1933–4.

The cotton seed sown in the Gezira in both seasons was Egyptian

Sakel, obtained from the Egyptian crop of the previous season. Black-Arm disease is only a minor pest in Egypt (owing to the sowing-period and the rainfall being very different from those of the Sudan), but in order to render negligible any seed-borne infection that might be carried into the Sudan, all the seed was dusted with a proprietary mercurial bactericide called Abavit B. This treatment ensured that any extensive Black-Arm infection appearing on the crop in the Gezira must have come from an extraneous source and was not the result of a seed carry-over.

Season 1932–3

Cultural and rainfall details.—Sowing of the crop began at the beginning of August, but was repeatedly interrupted by the heavy rains that fell during that month.

When the season started it was generally believed that the immediate source of the initial infection was the infective debris which lay on the immediately adjacent old cotton-land. This fallen debris consisted of the leaves, stems, boll-cases, and seed-cotton which remained on the ground after the cotton was cut out. The seed-cotton would be a particular source of danger, because it would give rise during the rains to infected cotton seedlings which would act as a potential source of infection to the new crop, the driving rains, as shown by Faulwetter [1] in America, Massey [2] in Sudan, and Hansford [3] in Uganda, being the vehicle of transmission between these infected seedlings and the new crop. In consequence of this all tenants were given orders by their inspectors to start sowing on the angaia of the howasha *farthest away* from the previous season's cotton-land, and as this sowing was continually interrupted by rains, it is obvious that, in any particular howasha, there would be cotton of varied sowing-dates with a concentration of the earliest sown on the side of the howasha *farthest away* from the old cotton-land.

The general rainfall of the Gezira during the season 1932–3 can be divided into five main periods: 1st period, Aug. 6–8; 2nd period, Aug. 20–1; 3rd period, Aug. 29–31; 4th period, Sept. 5–7; 5th period, Sept. 17–19.

In all these periods driving rains occurred, though, of course, the severity of wind and rainfall varied from place to place.

Details of the observations.—In this season 51 howashas scattered through the Gezira were kept under observation by native observers for the incidence and spread of Black Arm. Observations were made on selected ridges equally spaced through each howasha, and the sowing-date, total plants, and total infected plants per ridge per angaia, were recorded periodically.

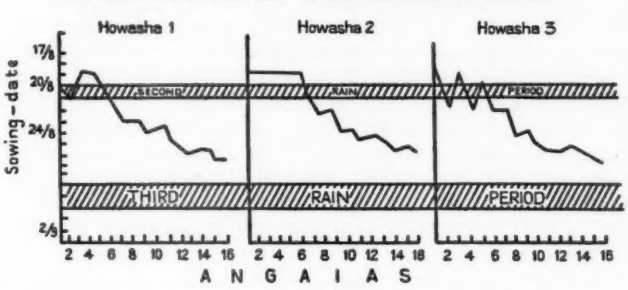
In this and the following season all the selected howashas were normal tenancies leased and cultivated by natives; no special cultural arrangements were made for the investigations, since their object was to determine the incidence and spread of Black Arm under the normal cultivation methods used by the natives in growing a crop of cotton in the Gezira.

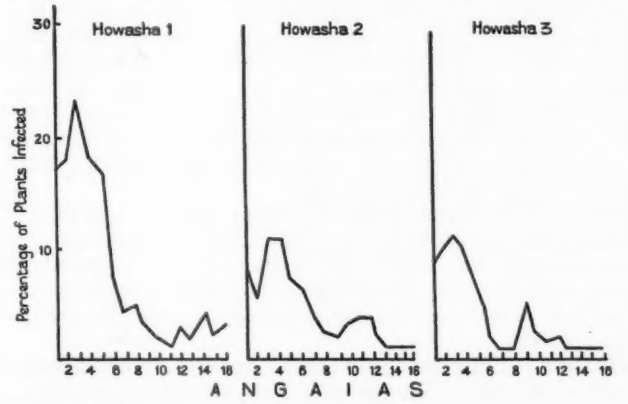
Results of the Observations

A. *Relation of incidence of Black Arm to sowing-date.*—It is obvious that the earlier the cotton is sown, the more rains it will be subject to, and since driving rain is the means of transmission of the disease to a

GRAPH I. *Effect of Sowing-Date on the Incidence of Black Arm*

(Observations made Oct. 17–23, 1932.)





Note: The sixteenth angaia lay nearest to last season's cotton-land.

healthy crop, the earlier will the cotton become infected provided there is an immediate source of infection.

This fact was definitely indicated in most of the howashas, where both early and later sown cotton occurred, and is strikingly illustrated in Graph I, where the sowing, beginning on the side farthest from the previous season's cotton-land, was interrupted by the second rain-period. It will be seen that the greatest infection occurs in the earliest sown cotton.

B. *Relation of incidence of Black Arm to proximity of old cotton-land.*—To decide if the immediately adjacent previous season's cotton-land is the main source of infection it is obvious that (*a*) a decision can only be made from a study of howashas that are *completely* sown in 1–2 days, so that all the cotton is above ground in time for the next rain-period, with a consequent avoidance of any concentration of the disease on a particular side of the howasha owing to earlier sowing on that side; and (*b*) that the driving rains must blow from the previous season's cotton-land to the new cotton crop.

Of the total howashas examined only 19 complied with these two conditions. Fourteen of these showed the greatest infection on the side nearest the previous season's cotton-land, and five an irregular distribution throughout the howasha. It is very noteworthy that among these 19 howashas nowhere was the heaviest infection on the side farthest away from the old cotton-land; and subsequent research has shown that where an irregular distribution of the disease occurs in a howasha, it is most probably due to the scattering, during a heavy wind, of infective debris on to the new land before the sowing of the crop.

Graph II illustrates the concentration of the disease on the side nearest the old cotton-land.

The fact that the infection does come from the immediately adjacent old cotton-land and not from some other source is indicated in Graph III. Here we have two howashas, No. 1 having a house on one side, and No. 2 having a howasha of old cotton-land alongside. Both had similar sowing-dates, but it will be noticed that howasha 1 has the greatest infection on the side farthest away from the old cotton-land, whilst the other has the heaviest infection on the side nearest the old cotton-land. The explanation is that the house has protected the nearest angaias in howasha 1 from the infection coming from the opposite old cotton-land, whilst in howasha 2, without this protection, the heaviest infection is on the side nearest the old cotton-land.

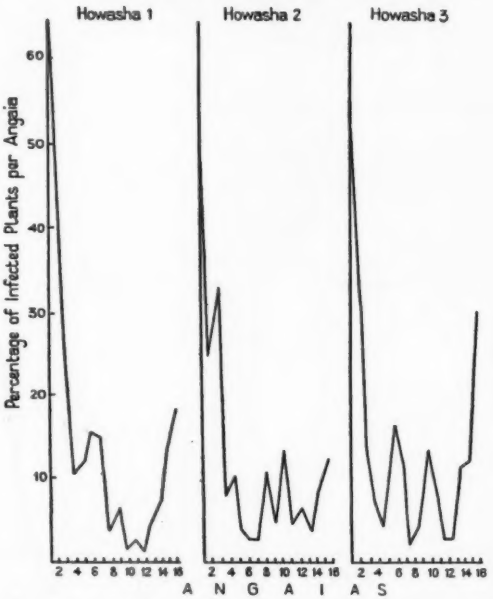
C. *Relation of incidence of Black Arm to rainfall.*—In field observational work by native observers on Black-Arm disease, it has been found safe to reckon that the initial infection of an area of cotton occurred from 12 to 14 days before the symptoms were first observed, and from this it is possible to associate the outbreak in most howashas with a particular rainfall.

From the date of observance of initial outbreak of the disease in most of the howashas under observation it appeared that the heavy rains of Aug. 29—31 were responsible for the main infection.

This is strikingly indicated in Graph IV, where the relation between the percentage of angaias sown and the number of howashas reporting initial infection is shown. It will be noticed that the major portion of the sowing occurred during the period Aug. 16–24, so that all this cotton would be above ground at the time of the third rain-period (Aug. 29–31). That this rain was responsible for infecting the cotton of this sowing-date is indicated by the fact that 12–14 days later (i.e. Sept. 11–14) the largest number (15 out of 28) of reports of initial outbreak was received.

The total number of outbreaks was small compared with the number of howashas under observation. This is due to the fact that not all observers observed equally well; only 28 were considered to have reported the disease sufficiently early for it to be described as an initial outbreak.

GRAPH II. *Effect of the Proximity of Last Year's Cotton-Land on the Distribution of Black Arm*



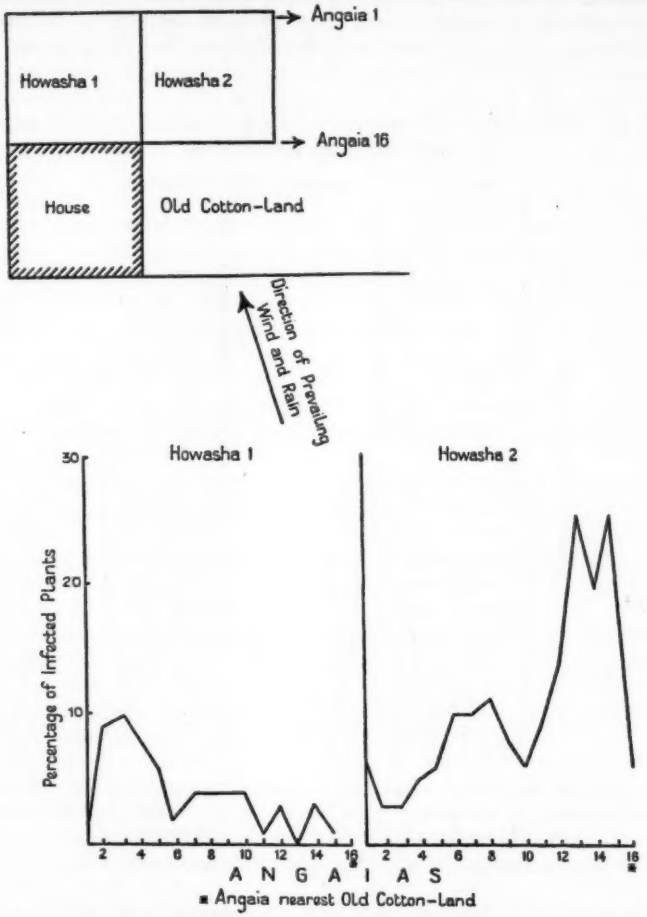
Note: In this case the sowing of the whole of howashas 1 & 2, and of the 15th and 16th angaias of howasha 3 was done on one day (Aug. 19). The remaining angaias in howasha 3 were completed on August 20.

In each case angaia No. 1 lies next to last year's cotton-land.

To summarize these data, and also to determine statistically if the adjacent old cotton-land was the main source of infection, or whether sowing-date was all important, a collection of data per howasha was made in which the sowing-date, percentage of infected plants per angaia, and the number of the angaia (i.e. indicating the position in the howasha) was known or could be interpolated. The number of angaias from which these data could be obtained totalled 384, and for the purpose of this examination angaia No. 1 was always the one nearest the previous season's cotton-land, and therefore angaia No. 16 the one farthest away from the old cotton-land.

The observations of percentage of infected plants present in these angaias were made between Oct. 5 and 15, and thus the amount of

GRAPH III. *Carry-over of Infection from the old Cotton-Land*



Black Arm present would be more or less stationary, as the immediate effects of the rain would have appeared by that date.

From these data it would thus be possible to find out if there was any correlation between—

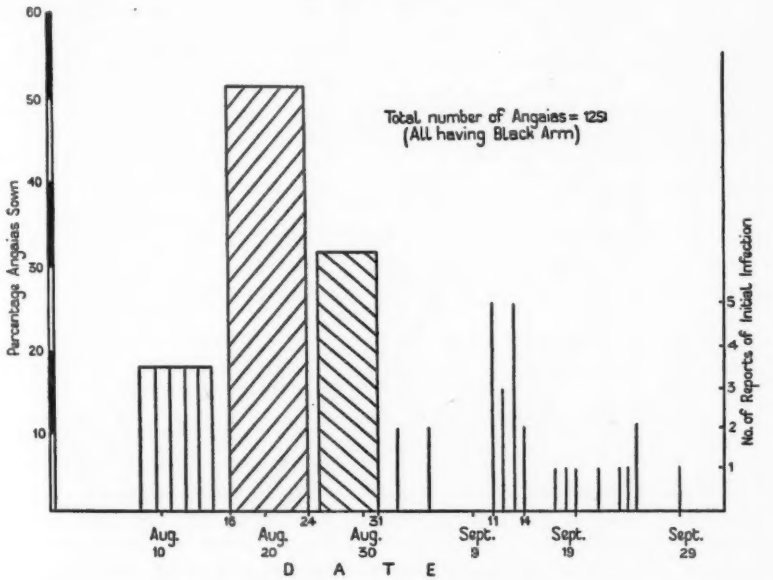
(*a*) position of angaia in howasha and percentage of Black Arm;
(*b*) position of angaia in howasha and sowing-date;
(*c*) sowing-date and percentage of Black Arm.

The above-mentioned data were submitted for statistical analysis, and gave the following results:

The partial correlation between the percentage of infected plants and angaia number (i.e. position in howasha), eliminating the effect of

sowing-date, is negative, but not significant. The probability is P = 0·2 to 0·1, i.e. the likelihood of this occurring by chance is between 1 in 5 and 1 in 10 cases, against 1 in 20 required for established significance. Hence one can safely conclude that there is a definite indication that Black Arm is worst nearest the old cotton-land, but it cannot be considered as established from these results alone. The ordinary correlation

GRAPH IV. *Relation of Amount of Cotton sown to Number of Reports of Initial Infection*



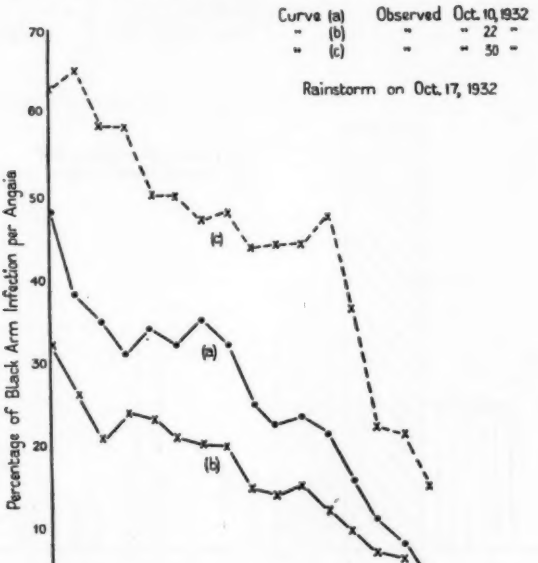
coefficients (for 384 observations) are: (1) *Percentage of infected plants and sowing-date* = 0·319 (highly significant). (2) *Percentage of infected plants and angaia number* = 0·051 (not significant). The incidence of Black Arm as a whole is not significantly related to angaia number, but as the ratio is positive there is a slight indication that the disease increases with distance from the old cotton-land (i.e. in the angaia which, in this season, happened to have more early-sown cotton). (3) *Sowing-date and angaia number* = 0·363 (highly significant), indicating, as has already been stated, that in the 1932–3 season much more early-sown cotton occurred in angaias farthest from the old cotton-land.

Summarizing, the slight indication of increased Black Arm with distance from the previous season's cotton-land is eliminated when sowing-date effects are considered, and, in place of it, there is a stronger indication of increased Black Arm nearer the old cotton-land. The significance of these indications, however, is not established.

Thus, as already stated, the evidence that the previous season's cotton-land is the main source of infection has been very considerably obscured in the season 1932–3 by the large amount of early sowing occurring on the side most distant from the old cotton-land.

D. *Relation of rainfall to the spread of the disease.*—Once the disease has arrived in the new crop the rate of spread will obviously depend on

GRAPH V. *Spread of the Disease due to a Particular Rainstorm*



Last season's cotton-land is next to Angaia 1.

the frequency and severity of the rainstorms. This was very clearly indicated in most of the howashas under observation and is illustrated in Graph V.

The curve (*a*) shows the percentage of infected plants on Oct. 10, 1932. An observation on Oct. 22, 1932 showed that the percentage of infected plants had *decreased*, owing presumably to the shedding of the infected leaves on some of the plants, in which case these plants would be classed as healthy (curve (*b*)). A rainstorm occurred on Oct. 17 and an observation on Oct. 30 (by which time the effects of this rain would be apparent) showed an increase in the percentage of infection (curve (*c*)). This graph also shows another striking case of the concentration of the infection on the side of the howasha nearest the previous season's cotton-land.

Season 1933–4

Cultural and rainfall details.—The sowing of the cotton under observation began on Aug. 1; owing to the satisfactory distribution of the rainfall, 67·7 per cent. was sown by Aug. 15 and 96·2 per cent. by Aug. 24. No special arrangements were made in this season for the sowing to begin on the side of the howasha farthest from the previous season's cotton-land.

The rainfall of the observational area during August and September may be roughly divided into four main periods during which a rainfall (more or less heavy) occurred in all areas under observation.

These periods are: (1) Aug. 3–6 (generally a small rainfall); (2) Aug. 20–2; (3) Aug. 27–31; (4) Sept. 9–12, and, in a number of the areas, a 5th period occurred on Sept. 19–22.

It is noteworthy that for a similar period in 1932 the rainfall could be divided into main periods of which the dates very closely correspond to those of this year.

In 1932 the main periods were: (1) Aug. 6–8; (2) Aug. 20–2; (3) Aug. 29–31; (4) Sept. 17–22.

It must be understood that the quantity of rain and the severity of wind during any period varied greatly from area to area; but there seemed to be a certain consistency in the date at which the heavier rain fell in the various areas under observation.

Details of the observations.—From the experience gained during the last season, it was felt that better and more accurate results would be obtained if intensive observations were confined to a few howashas, instead of the large number of the previous season. More intensive supervision could be given to the work, and it was hoped that the results would yield a more detailed account of the incidence and spread of the disease. In consequence, 16 howashas scattered through a badly infected area were kept under observation during this season. Observations were made on each of a total of 18 ridges, i.e. 6 groups of 3 ridges equally spaced through the howasha, and the sowing-date, total plants, and total infected plants were recorded periodically per ridge per angaia. It was thus possible to make a plan of the position in the howasha of the initial infection and its subsequent spread.

Results of the Observations

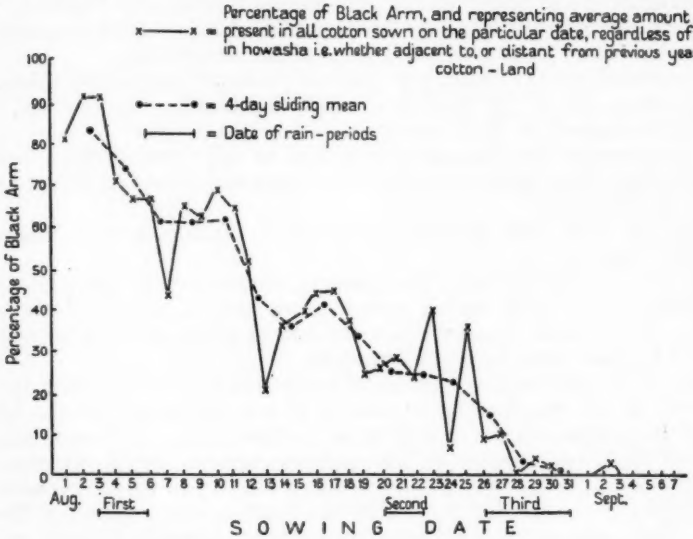
A. *Relation of percentage of Black-Arm infection to the sowing-date and rainfall.*—Given the sowing-date and the percentage of infected plants in the particular angaias having the same sowing-date, it was possible to construct a graph to show the relation between these two factors (Graph VI).

The date chosen for observation of the quantity of Black Arm in the angaias of various sowing-dates was about Oct. 15. The time between this and the date of the last rain was sufficient to allow its immediate effect to be apparent and recorded.

The curve showing the actual relation between these two factors indicates very strikingly the decrease in the amount of infection with

increasingly late sowing-date. The decrease indicated in this curve can be due either (*a*) to lack of infective material on the previous season's cotton-land, (*b*) to diminishing rainfall, (*c*) to climatic conditions unfavourable to the development of Black Arm, or (*d*) to the decrease in the quantity of cotton sown, with consequent unreliability of average figures obtained.

GRAPH VI. *Relation of Percentage of Black Arm to Sowing-Date*


Percentage of Black Arm, and representing average amount of B.A. present in all cotton sown on the particular date, regardless of position in howasha i.e. whether adjacent to, or distant from previous year's cotton-land
= 4-day sliding mean
= Date of rain-periods
Percentage of Black Arm
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7
Aug.
First
Second
Third
Sept.
SOWING DATE

Climatic conditions were suitable for the spread of Black Arm up to Oct. 15, in fact up to the end of November and possibly later, and observations had shown that the quantity of infective material on the previous season's cotton-land was considerably greater at the end of August and early September than during the first half of August. Most of the crop was sown from Aug. 9 to 15 and more was sown after Aug. 15 than before Aug. 9. There is thus an evident relationship between the amount of infection and diminishing rainfall, and the sowing-date of the cotton only affects the quantity of Black Arm in so far as the later sowings are subject to less rain.

The dotted curve is that of a four-day sliding mean and indicates the general trend of the relation between the two factors.

The definite 'steps' into which the decrease in infection falls are noteworthy: one occurs between Aug. 7 and 11, another between Aug. 13 and 19, and another between Aug. 21 and 25. It would seem that all cotton sown between the dates of these successive 'steps' had a similar amount of infection, and it is very striking to find that each step of sustained infection is followed 9–13 days afterwards by a heavy rain-period. It would appear that the cotyledons and leaves of the young

cotton plant first attain a condition in which they can become infected when the plants are about 11 days old, and not less than 9 days old in any case.

The existence of this 9–13 day period was also suggested by some of the records obtained in the previous season, i.e. 1932–3.

B. *Relation of spread of Black Arm to rainfall.*—A particular feature of the spread of the disease in the cotton of this season was the correlation between rapid increase and the occurrence of driving rains. Of the 16 areas under observation, 5 showed a rapid increase of the disease, and of these 3 had late driving rains. No information was available as to the type of rainfall in the remaining two. Nine areas recorded a slow increase of infection, and in every case this can be associated either with very slight late rains or with the complete absence of them. In some howashas it has again been possible to associate a particular increase in disease with a particular rainfall.

C. *Relation of incidence of infection to proximity of the previous season's cotton-land.*—Out of a total of 15 howashas having last year's cotton-land immediately adjacent to the new cotton, 10 areas showed initial infection on the side of the howasha nearest the old cotton-land, and in only one of these would it be expected that the initial infection would be on that side owing to the earliest sowing having occurred there.

Of the five areas showing either an irregular distribution in the howasha or initial infection on the side farthest from the old cotton-land, one was a probable case of infection by blown infective debris; three can be definitely associated with 'adverse' wind direction, i.e. blowing from a direction contrary to that from the old cotton-land to the new cotton; and there remains only one area for which no adequate explanation could be found for the irregular distribution of the disease.

Summary of the Results of the Two Seasons

(*a*) The infective debris on the immediately adjacent cotton-land of the previous season appears to be the main cause of an outbreak of the disease in the new crop.

(*b*) Provided that an adequate source of infection is present on this immediately adjacent old cotton-land, the sowing-date appears to be a major factor in governing the earliness of the infection.

(*c*) Since driving rains are the vehicle of transmission of the disease from the old cotton-land to the new, the severity and frequency of these must be a very important factor in determining the final severity of the disease.

(*d*) As the limits of the sowing-date of the cotton are narrow, for economic reasons, it is obvious that the only effective way to control this disease is to remove or render innocuous the infective material on the old cotton-land.

Research is now concentrated on this aspect of the problem.

Acknowledgements

I have to acknowledge my indebtedness to Mr. R. E. Massey, Government Botanist, Sudan Government, and Head of the Plant Pathological

Staff, for help in this work; to Dr. F. Crowther, late Plant Physiologist, Sudan Government, for assistance in the statistical analyses; and to Mr. M. A. Bailey, Director of the Agricultural Research Service, under whose direction these researches were made.

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VILLAGE WASTE

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1. THE loss that occurs in the almost complete failure to utilize the manurial value of habitation wastes, and the possibility of preventing this waste by the adoption of some kind of activated-compost system, such as that suggested by Fowler, has attracted a good deal of attention lately [1, 2, 3, 4]. This article describes an attempt to make use of local village refuse in this way in order to discover its possibilities.

2. Under the system that obtains at present all rubbish, whether house garbage or street refuse, is collected at intervals by a contractor, who employs his own men and carts, and removed to a dumping-ground, at some little distance, where it is supposed to be buried in pits or trenches. The cost of trenching, covering, and levelling the ground after filling, is borne by the village authorities. Practically no manurial value is obtained in this way, and except for its occasional use for filling up depressions, the disposal of this refuse is regarded as an expensive nuisance. One full-time labourer, or 26 man-days a month, was being employed in the present instance.

3. Arrangements were made to have this material delivered to a suitable locality on the College Farm.[1] Besides the material brought by these carts, a certain amount of estate rubbish was delivered by the College lorry, consisting of hedge-trimmings, refuse, and house garbage. The arrangements at this depot were made with a view to ensure complete aeration and thorough inoculation of the raw material with partially rotted material. All new material was mixed immediately on arrival with its own bulk of material which had been decomposing for a week. The heaps were maintained at a standard width, 3 ft., and at a height, which varied with the season, from 3–4 ft., being higher in the dry weather, when aeration was better. The moisture-content of the material varied, and when the rainfall was insufficient water had to be added as the heaps were made up, to keep them moist enough to decompose.

4. The arrangements made were as follows (Fig. 1): On either side of a central track, 12 ft. wide, heaps $5 \times 3 \times 3$ ft. were made. Each complete heap was allowed to remain for a week, when it was doubled. After another week it was divided, and half the heap was moved outwards to a second heap. At the end of the third week, these half-sized heaps in the second row were completed. The following week the process was continued to a third heap, from which the material was subsequently removed, half a heap at a time, to a dump where it was stored in bulk, and where a further slow process of decomposition occurred. After six weeks the process became continuous, and each working-day of the week the requisite number of third-row heaps were divided and half of

[1] As the authorities considered that this entailed a longer lead for the cartmen employed, they decided that a sum of 6 cents (3*d.*) a cart should be paid to the contractor for the extra work involved. It was not thought worth while contesting this charge, which was, in the writer's opinion, unjustified.

each removed to the main dump: they were then made up to full size from the second-row heaps. The second-row heaps were made from the first-row heaps, and the half of each first-row heap left was thoroughly incorporated with an equal quantity of raw refuse.

5. The system worked well. The loads were dumped right on the spot where they were wanted, and there was a minimum of carting. It is, of course, true that such a depot occupies a considerable area (Fig. 2), but this is unavoidable, as if the heaps are made too large, they do not

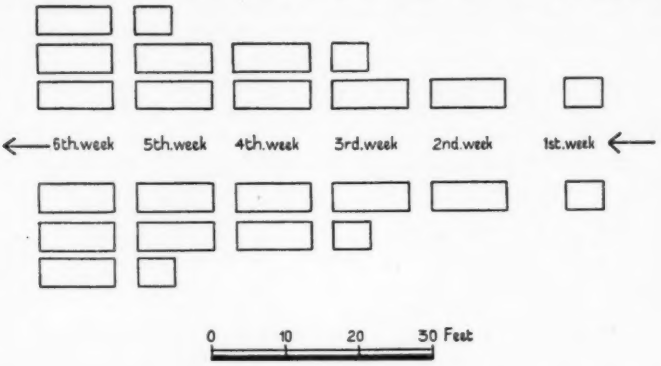

FIG. 1.

decompose properly. The material soon became thoroughly impregnated with fungal mycelia, temperatures rose very rapidly, and decomposition was pretty thorough.

6. Work started in December 1934, and the experiment was carried on uninterruptedly until the end of October 1935, a period of eleven months. The table below shows the quantities received, and the amount of manure made:

	Received						*Sent out Cart-loads (Finished compost)*	
	Cart-loads of rubbish		*Lorries (estimate)*		*Total cart-loads*			
	No.	*Cost of carting*	*No.*	*Equiv. in carts*	*No.*	*Weight (estimated) tons*	*No.*	*Weight Actual tons*
		$						
Dec.	201	12·06	13	26	227	80	22	10·00
Jan.	228	13·68	13	26	254	89	..	..
Feb.	225	13·53	20	40	265	92	1	0·30
March	275	16·53	20	40	315	110	1	0·30
April	265	15·81	20	40	305	106	19	5·45
May	214	12·87	32	64	278	97	20	8·38
June	182	10·95	20	40	222	77	128	57·95
July.	209	12·54	20	40	249	87	19	10·65
Aug.	199	11·97	20	40	239	83	5	2·50
Sept.	196	11·76	20	40	236	82	..	..
Oct.	201	12·06	22	44	245	85	23	14·00
	2,395	143·76	220	440		988	238	109·53

7. It was estimated that at the end of October there were about 50 tons of partially complete manure still at the depot.

8. In considering these figures, it has first to be noted that all the

material received did not go into the dumps. There was a large proportion of inert material in the shape of tins and iron utensils, bottles, whole or broken, of all sizes, and india-rubber shoes. Random weighments of this inert material showed 960 lb. collected from eight carts, which, at 7 cwt. to the cart, is over 15 per cent. Most of this material had to be picked out and buried in deep pits. This was expensive, for it implied a considerable and increasing lead. It was not expected that there would be such a large number of tins, but tinned milk is in regular use,

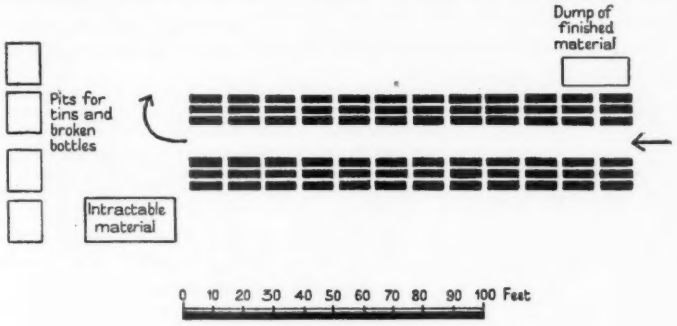

FIG. 2.

and other tinned material enters largely into the diet of the West Indian. It was not possible to remove the broken glass completely, and several casualties due to cut feet have occurred among the field labourers working barefooted in the lands manured with this material. In addition, there was what was called 'intractable' material, such as coco-nut husks, palm fronds, and large branches. This was removed to a heap (Fig. 2), which was turned over twice a year, when any partially rotted material could be collected and incorporated into the regular heaps.

9. After the removal of this useless material, the residue went into the heaps for fermentation. This residue contains such a varying amount of moisture, that it is very difficult to make out any accurate balance-sheet of incomings and outgoings. The samples analysed in August gave from 29 to 40 per cent. of moisture, whilst in March some analyses showed as little as 11 per cent.

10. The problem is further complicated by the actual loss of material that occurs during the process of composting, which may be considerable if this is continued for long. Below are the measurements taken of some heaps in the depot which were originally all similar in size:

Heaps one week old: $10 \times 3{\cdot}25 \times 2{\cdot}5$ ft. = 81·2 cu. ft.
Heaps two weeks old: $10 \times 2{\cdot}5 \times 1{\cdot}5$ ft. = 37·5 cu. ft.
Heaps three weeks old: $10 \times 2{\cdot}25 \times 1{\cdot}25$ ft. = 28·1 cu. ft.

This reduction in size is accompanied by some increase in density, though probably not enough to make up for the loss, and of course the heaps may be losing moisture. The average volume-weight ascertained for such compost was from 20 to 30 lb. per cubic foot.

11. The question of water is important from the standpoint of expense. Water was added, though probably rather more than was necessary. An inspection of the heaps in June gave the impression that they were too dry, and an experiment was carried out in which the heaps were thoroughly soaked each time they were turned over. Half the number of heaps were allowed to remain a fortnight, instead of the usual week, in each stage, so that the stages of manufacture were not completed for eight weeks: the other half was turned weekly. This was to ascertain whether a longer period of manufacture would give a better final product. Two months after the start[1] the heaps were sampled, and were compared with compost which had been made in the ordinary way, i.e. by moistening occasionally.

	Soaked and turned at 14-day intervals	*Soaked and turned at 7-day intervals*	*Not soaked and turned at 7-day intervals*
Non-analysable matter .	32·7	21·5	34·7
Water . . .	29·9	40·6	27·4
Ash	29·7	29·0	30·9
Organic matter . .	7·7	8·9	7·0
Nitrogen . . .	0·256	0·294	0·268

It appears that the need for water to promote decomposition is likely to be exaggerated.

12. The quality of the manure may now be considered. Sampling was not easy, for it was found that even in the finished material there were many small pieces of tin, wood, glass, iron, and stones, which had to be removed before the manure could be analysed, and this foreign matter, where it was separately weighed, was found to be considerable, averaging 29 per cent.

Analyses of Village-Refuse Compost

	June 1934	*March 1935*	*June 1935*	*April 1936*		*Average*
	1	2	3	4	5	6
Non-analysable matter (of no manurial value) .	(25)	(25)	35	33	19	28
Moisture . .	24	16	27	25	34	25
Ash . . .	33	18	31	28	30	28
Organic matter .	18	40	7	15	17	19
Percentage on oven-dry material (of complete sample)						
Nitrogen . .	0·64	1·11	0·27	0·71	0·86	0·71
Phosphoric acid .	..	..	0·18	0·38	0·53	0·36
Potash . .	..	..	0·23	0·76	0·88	0·62

[1] The rainfall during this period was as follows: June, 3·79; July, 7·75; August, 13·74 inches.

For comparison a few other analyses are quoted:

	Average Ceylon street-refuse compost [5]	*Maize-straw compost*	*Adco from cane-trash*	*Average pen manure Trinidad*
Non-analysable matter (of no manurial value)	8	..	..	..
Moisture . . .	46	68	74	75
Ash	34	10	10	16
Organic matter . .	12	22	16	9
	Percentage on oven-dry material			
Nitrogen . . .	0·62	..	..	1·89
Phosphoric acid . .	0·40	..	..	1·25
Potash . . .	0·47	..	..	2·13

It will be noticed that there is a wide range of variation in the quality of the village-refuse compost, in spite of care in taking the samples. No. 3 is particularly poor; it was reported at the time that the cartmen were bringing in very poor material in their endeavour to earn as much as possible. Nos. 4 and 5 are taken from manure now being made in exactly the same way by the Government nurseries at St. Augustine. The cartmen are not paid by the cart, and the material they bring is undoubtedly better; and water is laid on. The high figure for non-analysable material in No. 4 is due to the presence of a large stone.

The quality of the compost is, however, not very high, though it is noticeably drier than most of the manures with which it might be compared. The total organic matter is low, due in the main to the very high proportion of ash, largely the earth swept up with the rubbish. A great many of the roads in the locality are oiled, and this figure is higher than was expected. This extraneous matter adds a great deal to the cost of handling and carting, besides slowing down the fermentation process.

13. The value of the manure, based purely on its manurial ingredients, is calculated below:

	Per cent. average	*Value per unit*	*Value*
			$
Nitrogen . .	0·53	1·50	0·80
Phosphoric acid .	0·21	1·00	0·21
Potash . .	0·46	1·47	0·67
Total . .			1·68

Its real value, however, is considerably higher than this, for it is an organic manure, and opinion to-day is more than ever in favour of bulky organic manures, supplemented, where necessary, with inorganic manures, as a means of maintaining soil condition and raising healthy crops. Considerable herds of cattle are kept in Trinidad to assist in turning cane-trash and similar substances into manure, so convinced are the planters of the need for organic manures. If it is accepted that such a manure is necessary, and the writer is convinced that it is, on the soils of

the College Farm, then this system indicates a way in which it can be obtained.

14. The cost of making this compost is as follows: The routine work at the depot consists in turning over a certain number of heaps: incorporating the new material in the first-row heaps: removing the completed half-heaps to the dump: carting away the inert material and digging pits to receive it; and carting water during the dry weather. It was calculated, after a few weeks' trial, that the necessary labour would amount to about 75 man-days a month, at a cost of about $35·00, or $380·00 for the eleventh-month period. Animal power was estimated at $70·00 a year —a total of $450·00: actually the total cost for labour for the period was $481·00.[1] For this sum a total quantity of rather over 150 tons of compost was made, at a cost therefore of $3·20 a ton. This seems excessive, but could be reduced if work was carried out on a larger scale.

15. There is another aspect from which this system must be examined, namely, whether it satisfies sanitary standards. One of the main troubles in the disposal of habitation wastes is the breeding of flies. It is claimed by some advocates of this composting system that the heat developed in the heaps—temperature about 65° C.—is sufficient to destroy fly larvae. This was not found to be the case, but there is no doubt that the nuisance from this is very much reduced, and that there need be no complaint on this ground, or on the ground of objectionable smells.

16. Some experiments were carried out [6] to ascertain what emergence of flies might be expected from the heaps. After the heaps had been built up they were left exposed for varying periods of time, up to a week, when they were covered with fly-proof cages. These were left on until emergence had ceased, which happened in about 3 weeks from the time the heap was built. The table below shows the total number of flies and the total number of house-flies that emerged from these differently treated heaps. The figures are the average for each of two heaps similarly treated.

Treatment	*Total Flies*	*Musca*
Covered at once . . .	1,328	606
Covered after 24 hours . .	636	482
Covered after 3 days . .	358	253
Covered after 7 days . .	326	307

17. These figures indicate that the material is fairly heavily infected when it reaches the depot, but that it does not form an attractive *nidus* for oviposition, once it has been made up into a compost heap. What the experiments have shown is that fly larvae can stand much higher temperature than was imagined. Most of them are to be found, naturally, near the surface of the heap, but they have also been found well inside a heap which was registering 70° C.

18. The system thus satisfies all requirements except that of cost, and this, it has been suggested, would be reduced, if work was carried out on a larger scale. The authorities would be saved the expense of the

[1] The contractor was paid $144·00, but this is not taken into account as it would not have to be paid in ordinary circumstances.

labour which they now have to employ to bury the refuse, and this saving would reduce the cost of the compost. In this experiment the method of payment by carts also caused a certain amount of sharp practice on the part of the cart-drivers, who tended to bring short weight and poor material.

19. The real trouble is, however, the poor quality of the raw material, to which allusion has already been made. Civilization has brought the tin and the bottle, and increased considerably the difficulty of disposing of habitation wastes. It has been suggested that the material with which the experiments were carried out was not typical, but in Trinidad, at any rate, it is probably fairly representative. Conditions in the East, where most work has been done on this problem, are of course very different. Many castes in India use leaf plates, fresh for each meal, a practice which is bound to increase the organic matter in the refuse. Tinned food is rarely eaten, and bottles of all kinds are much too valuable to be thrown away. Consequently there is much less inert matter, and less cost in manufacture. In Trinidad a method would have to be devised to eliminate some of this extraneous matter before composting was begun.

20. An experiment was carried out at the request of the sanitary authorities in a neighbouring village, where there was an outbreak of enteric. Here the raw material was village rubbish, with a preponderating quantity of cow-pen manure, which, owing to the danger of fly infection, it was thought desirable to remove at short intervals. This material fermented vigorously, and produced a far better compost than that obtained at the College, under the conditions described above.

Summary

21. The preparation of compost from village rubbish in Trinidad is shown to be feasible, but not economic. The high proportion of inert and often objectionable material increases the cost of manufacture and reduces the quality of the finished product. Evidence is given that the system outlined satisfies sanitary requirements.

Acknowledgements

The analyses quoted were all made in the Chemical Department of this College by the courtesy of Professor Hardy. The Reader in Agriculture, Mr. Paterson, supervised the experiment in the absence of the author.

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NOTE *by* RUDOLPH. D. ANSTEAD

(*Retired Director of Agriculture, Madras Presidency, South India*)

This experiment at the Imperial College of Tropical Agriculture was instigated at my suggestion during my visit to Trinidad in January 1934, and so I may perhaps be permitted to make a few comments.

Professor Wood has carried out a most valuable and instructive piece of work and thoroughly demonstrated the possibilities of this method of dealing with village refuse, usually regarded as an expensive nuisance. The College was handicapped in several ways, and I am convinced that it is work for a municipality and not for a farm. A farm can deal with its own waste material, but is not really suited for dealing with municipal refuse, unless this is delivered to it free of cost and reasonably free from useless material. A public body must dispose of its refuse in any case, and the whole question centres round whether it is possible to *utilize* such material for the benefit of agriculture, and not merely *dispose* of it. The usual disposal methods employed are as a rule costly, insanitary, and unsatisfactory. The method recommended provides for satisfactory disposal, and at the same time gives a product which has some monetary value, however small. In South India, where conditions are admittedly more favourable than they are in Trinidad, the monetary value of the compost is often found to cover the whole cost of the process, and thus reduce the rates.

The cost of the process at the College has been high, but were it carried out by the municipality this would be considerably reduced, and if done on a large scale still further savings could be effected. The main difficulty appears to be the unsuitable nature of much of the refuse, and this was intensified in this experiment by the system of collection employed. In the hands of the municipality the difficulties could be reduced by separate collection of materials like bottles, tins, and boots, and there would not be the temptation for cartmen to bring unsuitable material merely to earn more money. Too much notice should not therefore be taken of the cost of manufacture at the College under the conditions imposed on them. What is of importance is the fact that Prof. Wood says that 'the system worked well'.

The necessity for watering the heaps is, I think, apt to be exaggerated, and except, perhaps, during a prolonged dry spell it should be quite unnecessary.

In considering the economics of the process other factors should be taken into consideration besides the simple formula:

$$\text{Cost of manufacture} = \text{Value of resulting compost based on its nitrogen-content} \pm X,$$

where X is perhaps a loss. On this side of the equation credit must be allowed for sanitary advantages and savings in the health departments, and the fact that material is being produced which can be utilized for agricultural purposes. The compost made at the College was very variable in quality, but this could probably be corrected by better methods of collection of the waste material. Even so, however, it has very considerable manurial value. These activated composts have proved to be very valuable fertilizers. The plant-food in them is readily and quickly available, and their value must not be calculated on their nitrogen-content only; it really consists in the humus-content, and the effect of this on the health of the crop. As Prof. Wood says, if it is accepted that organic matter is necessary, then this system does indicate a way in which it can be obtained.

The experiment at the College Farm has indeed indicated the lines which should be followed, and it appears to me that with this information before them a public body like a municipality should be able to devise a method of dealing with its waste products on biological lines which would prove economical and convert such waste into wealth, as is being done in many other countries.

(*Received June 15, 1936*)

A MANURIAL EXPERIMENT ON BANANAS

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IN a previous note[1] attention was drawn to the need for manuring bananas in Trinidad, if any profit was to be obtained. A more detailed trial has now been made to see what effect follows from the addition of potash, or potash and phosphoric acid, to a general organic manure, on the quality and the quantity of the banana crop. The variety used was the Dwarf Cavendish, because the land was affected with Panama disease, and although this banana is not grown for export, the 'count' system of valuation was adopted. The 'count' bunch is one of 9 hands or over. Nothing extra is given for bunches containing more than 9 hands; an 8-hand bunch counts only as ¾ of a bunch, and a 7-hand, if accepted, is only a ½-bunch. Bunches containing less than 7 hands are generally not accepted.

Lay-out.—The experiment was carried out in Field 33 on the College Farm. The three treatments were replicated four times, the plots being randomized in each block. Each plot was square and comprised 16 trees, which were all numbered. Shallow trenches were dug between plots, to assist in demarcating them. The trees were planted 10 ft. apart each way (435 to the acre), so that each plot was 1,600 sq. ft.

Soil.—The soil is a detrital sandy loam, somewhat reworked by stream action, derived from quartz-schists which comprise the main rocks of the Northern Range of Trinidad. Its content of coarse and fine sand is about 50 per cent.; it is slightly alkaline in reaction, and contains only about 1·5 per cent. of organic matter in the surface 6-inch layer. Available potash is notably deficient (35 p.p.m.K_2O) and available phosphate slightly deficient (30 p.p.m.P_2O_5).

Treatments.—The standard plots were manured as follows:

Treatment I.

August 1932, 100 lb. pen-manure per stool (20 tons an acre).
July 1933, pulverised limestone at 6·6 tons an acre.
October 1933, 100 lb. pen manure per stool.
October 1934, 2 lb. sulphate of ammonia per stool (8 cwt. an acre).
January 1935, 2 lb. sulphate of ammonia per stool (8 cwt. an acre).

Treatment II. As above, but *in addition*, muriate of potash was given on the following dates: Aug. 1932, 1 lb., Oct. 1933, 1 lb., Jan. 1934, 1 lb., Oct. 1934, ½ lb., Jan. 1935, ½ lb.

Treatment III. As No. II, but *in addition*, superphosphate was given: Aug. 1932, 2 lb., Oct. 1933, 2 lb., Jan. 1934, 2 lb., Oct. 1934, 1 lb., Jan. 1935, 1 lb.

Results

The following are the yields obtained from the plots:

[1] *Tropical Agriculture*, 1932, **9**, 352.

TABLE 1. *Yields of 'Count' Bunches*

(Totals for five years)

Treatment	*Block 1*	*Block 2*	*Block 3*	*Block 4*	*Total*
Basic	15·25	26·75	25·75	33·75	101·50
+Potash . . .	44·25	37·00	41·75	47·75	170·75
+Potash and phosphoric acid	27·00	27·25	37·75	48·75	140·75
	86·50	91·00	105·25	130·25	413·00

Significant difference between totals, 36·7 bunches (P = 0·05).

The gain due to the use of potash is significant at the 1 per cent. point. There is apparently no benefit from using phosphoric acid; and there is a strong probability that its use has actually depressed the yield.

TABLE 2. *Yields of 'Count' Bunches per acre*

Treatment	*For 4 plots (5 years)*	*Per acre (5 years)*	*Per acre per annum*
Basic (N)	101	691	138
Basic with muriate of potash (N+K) .	170	1,162	232
Basic with muriate of potash and superphosphate (N+P+K)	140	958	192

The cost of the additional dressings of manures and the value of the increases in yield obtained from them are shown in Table 3:

TABLE 3

	Increase bunches	*Value* $	*Dressing*	*Cost* $	*Profit*
Basic	..	..	..	..	..
Basic and potash . .	470	188	1,740 lb. M/P	18	170
Basic, potash and phosphoric acid	265	106	1,740 lb. M/P and 3,480 lb. super.	36	70

The figures for profit are obviously subject to the same experimental error as the figures for yield in Table 1.

It may be noted that the above only takes into account the 'count' bunches. The object of any scheme of manuring should be to produce the highest possible proportion of nine-hand bunches, and the curve plotted in Fig. 1 shows the effect of the potash in increasing the proportion of them. It is based on the yields of the last two years only.

Discussion.—The stools were in a poor condition when the experiment started, and it was decided to give a basic dressing of about 20 tons of pen manure per acre, as it was thought that without this, growth would be unhealthy, and complications would be introduced from the ravages of the *Tomarus* beetle (cf. *Tropical Agriculture*, 1935, **12.** 327). The general improvement in the health of the stools was marked, and the

plots have maintained a healthy normal growth throughout. It was noticed that a rather large proportion of the stems failed to stand up to the weight of the bunches. This is apparently a well-known feature of Cavendish bananas under heavy manurial treatment. No differences

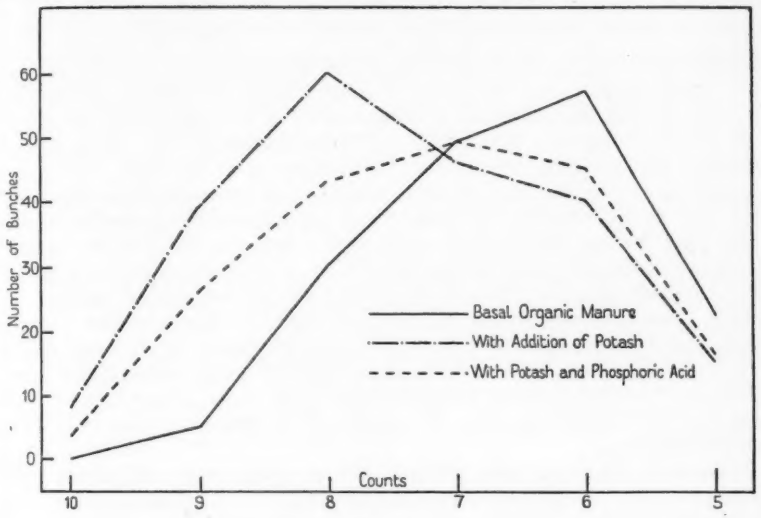

FIG. 1.

were observed between the plots in the first two years, presumably owing to the initial dressing of pen manure, but latterly the effect of potash has been most marked, and has certainly proved profitable. The action of phosphoric acid is not so marked, but it appears to depress the yield. A similar result has been observed in the manuring of sugar-cane, in the neighbourhood, where the use of phosphoric acid on soils of intermediate lime-status leads to a depression in the yield.

At the suggestion of a colleague, the precaution was taken of scratching the number of the bunch on the stem with a sharp style, as soon as possible after it appeared, and recording it forthwith. This enabled track to be kept of bunches that were stolen, and it also reduced the possibility of the incorrect allocation of bunches from the plots.

Conclusions.—It is clear that in these conditions the use of potash has brought about an increase in yield, which has been most profitable. The figures given in Table 3 refer only to 'count' bunches, but the larger number of small bunches, which can be sold locally, obtained from the plots receiving potash, will increase this figure.

The use of phosphoric acid is not recommended. It cannot be said definitely that its use has actually depressed the yield, but it certainly has not increased it, and the extra expense is not justified.

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THE COMPOSITION OF GRASS LAID UP FOR WINTER KEEP

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Introduction.—The laying up of grass for winter keep, i.e. the enclosure of pasture fields in July or August, with a view to obtaining a substantial growth for the maintenance of outlying stock during winter, is not as yet common practice. In view of the present tendency to reduce labour charges, and the great decline in the acreage of arable land, which has caused, *inter alia*, a reduction in the amount of straw available for feeding, it seems probable that this means of conserving grass for winter keep may find an established place in the farming routine of counties enjoying moderate climatic conditions. In Northumberland the laying up of winter grass appears to be carried out in haphazard fashion; in many cases only sheep are excluded during late summer, the pasture being lightly stocked with cattle. The primary object appears to be the provision of clean land and a good 'lie' for ewes from October to January. Nevertheless, as hand-feeding is not usually resorted to until late winter, it is obvious that the quality of the grass is a very important consideration.

The term 'winter grass', as used here, refers to grass which has been grown during the previous autumn, although such grass may include some growth made during the winter months. The amount of such winter-grown grass present may be sufficiently large in the southern counties to be of practical importance, but can seldom be anything but negligible in NE. England. The few investigators who have so far interested themselves in this subject have dealt almost exclusively with winter-grown grass. In discussing methods of management and manuring calculated to produce a supply of winter grass, Stewart [1] recommends that the herbage be uniformly grazed down or mown so that by the beginning of October there is a level green sward an inch or two long. An all-round mixture of manures should then be applied, and all stock kept off until it is wanted for ewes and lambs in January. It is obvious that under such management conditions, even in the south of England, a large part of the grass available in January must have been winter grown. Recent work carried out by Woodman and Oosthuizen at Cambridge [2] is also largely concerned with winter-grown material, the yield, composition, and digestibility having been determined in pasture grass produced by unrestricted growth over the following periods: (1) end July 1932 to Dec. 1932; (2) end Aug. 1932 to Jan. 1933; (3) end Sept. 1932 to Feb. 1933; (4) end Oct. 1931 to March 1932. Although the grass produced during the last two periods was of relatively high feeding-value, Woodman admits that the yields were too low to have any significance in farming practice, and states that it would be necessary to discontinue grazing at the end of July in order to produce sufficient herbage for use during the winter. The

grass grown during the first of the above periods is comparable in certain respects with the material used in the work to be described, but Woodman does not appear to have ascertained the variation in quality which may be expected to occur during the winter.

The object of the following investigation was to determine the effect of weather conditions, and of the selective grazing of stock, on grass that was grown during late summer and autumn for providing winter keep, that was practically mature in October, and that at no period contained any considerable proportion of winter-grown herbage.

Experimental

For this investigation the authors were able to secure the use of two 3-acre plots on Roundabouts, Cockle Park. These plots, amongst others, had been used between 1929 and 1933 for an investigation into the 'intensive system' of grassland management; the treatment, manurial and otherwise, which the plots received during this period has been described elsewhere [3]. The soil, which is typical of large areas of Northumberland, is a clay loam derived from the worst type of Boulder Clay and has the following analysis:

	Per cent. of air-dry sample		*Per cent. of air-dry sample*
Coarse sand	15·20	P_2O_5, HCl-soluble	0·095
Fine sand	32·80	K_2O, HCl-soluble	0·177
Silt	12·28	P_2O_5, available	0·012
Clay	24·47	K_2O, available	0·012
Moisture	2·08		
Carbonates	nil	pH	6·34
Loss by solution	1·40		
Difference	11·77		
	100·00		

It may be noted that four years of intensive treatment had caused marked changes in the character of the sward. A botanical examination of the plots made on Nov. 26, 1934, early in the winter period, showed that in both plots the predominant herbage-component was Yorkshire Fog, this grass covering approximately 70 per cent. of the ground. Only two other species, viz. cocksfoot and creeping buttercup, made any substantial contribution, although occasional plants of perennial rye-grass, crested dogstail, Aira spp., Agrostis spp., and narrow-leaved plantain, together with such weeds as dandelion, sheeps sorrel, and acrid buttercup were noted. Wild white clover, one of the most important herbage components on this land prior to the application of intensive treatment, occupied only 5 per cent. of the ground. The contrast between the 'intensive' herbage of the experimental plots and that of adjacent land which has received only basic slag at the usual rates for many years, and contains a preponderance of wild white clover and perennial rye-grass, was most striking. That this marked botanical difference has very little effect on the relative nutritive values of the two swards has been shown by Thomas and Elliott [4].

Both plots were grazed with blue-grey bullocks and sheep during the summer, the management being such that there was very little grass on either by Aug. 4. On this date all stock were taken off, the droppings were spread with a chain harrow, and the plots laid up. On Oct. 27, one plot was stocked, and thereafter grazed at the discretion of the farm steward, who had been requested so to manage the grass that some 'keep' should be available throughout the winter, and that adequate analytical samples should be always available.

Prior to the experiment proper, samples were taken at monthly intervals throughout the summer of 1934, with a view to ascertaining the quality of spring and summer grass yielded by the plots; a standard was thus secured with which it might be possible to compare samples taken during the following winter, and which would determine the validity of comparisons made with winter grass obtained from other areas. In taking summer samples, the two experimental plots were treated as one, 5 cutting areas, each of 4 sq. yds., were located at random, cleared with heavy garden shears on April 4, 1934, and fenced with netted hurdles, which provided maximum access of light but were strong enough to exclude all classes of stock. The first samples were taken on May 2, 1934, and on the same day the fencing was transferred to five further areas which had been randomized and cleared. The samples in all cases constituted the total yield of the cutting areas and were conveyed to the laboratory in suitable bags. This procedure was continued throughout the summer, new areas being cleared and cut at regular intervals of 28 days. Six cuts in all were obtained.

On Oct. 17 the first winter samples were cut from 5 areas, each of 4 sq. yds. taken at random on both of the experimental plots. Further samples were obtained at 28-day intervals throughout the winter, the last cutting date being April 3, 1935. For reasons already indicated, the necessity for fencing did not arise during the winter period, samples being taken immediately after the randomization of the cutting areas.

The samples were dried in an air-oven at 65–70° C., and ground in a power-mill over a $\frac{1}{32}$ in. screen. Crude and true protein, ether extract, fibre, ash and ash-constituents were determined by the usual analytical methods. The method of Wedemeyer was used in determining the digestion-coefficients of the crude protein. Two-gram samples for determining moisture were weighed simultaneously with all portions required for other determinations, the moisture-content being calculated on a single weighing after an arbitrary drying-period of 24 hrs. in an electric oven at 100° C. Woodman's formula [5], which assumes a normal silica-content of 1·72 per cent. for clean grass, was used in making the necessary corrections for soil contamination.

Meteorological Data

Rainfall, sunshine, and temperature data relative to the 28-day cutting periods, together with the mean rainfall and sunshine figures for corresponding periods over the years 1924–33 are embodied in Table 1.

TABLE 1. *Meteorological Data for Period of Experiment: Cockle Park Weather Station*

Period	Rainfall (inches)	Average rainfall for 10 yrs. 1924–33 (inches)	Sunshine (hours)	Average sunshine for 10 yrs. 1924–33 (hours)	Temperature		
					Mean grass min. (°F.)	Mean screen max. (°F.)	Mean screen min. (°F.)
April 4–May 1, 1934	5·54	1·79	111·6	125·5	36·6	50·3	36·4
May 2–May 29	1·15	1·98	162·2	133·0	37·8	57·8	40·4
May 30–June 26	1·69	2·32	154·6	176·3	45·2	62·5	45·9
June 27–July 24	2·78	2·43	198·5	152·4	49·0	69·6	51·2
July 25–Aug. 21	4·04	3·35	138·9	137·8	44·1	66·0	49·5
Aug. 22–Sept. 18	1·13	1·88	159·3	138·5	43·4	64·2	43·0
Sept. 19–Oct. 16	1·79	2·56	85·6	105·0	41·0	58·2	43·9
Oct. 17–Nov. 13	5·59	2·45	78·9	95·4	35·1	47·5	37·3
Nov. 14–Dec. 11	2·92	2·60	17·7	49·5	38·9	48·6	41·0
Dec. 12–Jan. 8, 1935	3·76	2·12	25·3	45·6	36·4	46·5	38·6
Jan. 9–Feb. 5	1·48	1·93	36·7	54·7	30·7	43·8	32·8
Feb. 6–March 5	1·88	1·69	61·0	71·8	32·1	44·9	34·4
March 6–April 2	0·79	1·68	88·4	106·7	33·9	48·9	37·1

The total rainfall from April 4 to May 1 was exceptionally high; otherwise the spring of 1934 was mainly dry and bright. Temperatures were rather low during April and May. The weather was unsettled after mid-July, and from then onwards, and throughout August and September, there were frequent showers with average sunshine, and temperatures slightly above normal.

The experimental period opened in October with pastures looking fresh, the weather during this month being mainly bright, with occasional showers of sleet and snow at the end of the month.

November was dull, damp, and foggy, and the rainfall was approximately 50 per cent. higher than the average of 37 years recorded at Cockle Park for that month. Ground frosts occurred from the 1st to 4th and 6th to 9th, inclusive.

December was characterized by an exceedingly high rainfall, little sunshine, and abnormally high temperatures. Grass looked particularly green and fresh during this month.

The weather during Jan. 1935 was mainly dry and mild, with sharp frosts between the 7th and 9th and wintry conditions during the last few days of the month. Between the 24th and 27th there was a NW. gale accompanied by a snowfall of 4 in., which lay until the 29th.

February was unsettled and stormy with high W. and NW. winds. The first and last weeks were cold, with ground frosts; during the remainder of the month temperatures were above normal. Snow fell between the 23rd and 27th.

The first five days of March were wet, but less than 0·75 in. of rain fell during the rest of the month. Winds were light and variable in direction. Ground frosts were experienced on eight days, but temperatures were generally high.

The weather during the winter of 1934–5 might be described as 'muggy'. The rainfall from Oct. to Dec. 1934 was well above the average for the previous ten years. Throughout the winter the amount of bright sunshine was lower and the temperatures higher than the averages.

Results

The composition of grass samples taken from the two plots during the winter of 1934–5 is shown in Table 2, each figure being the mean of analyses made on five replicate samples.

TABLE 2. *Composition of Grass Samples, 1934–5. Percentage of Soil-free Dry Matter*

PLOT A (ungrazed)

	1934		1935					
	Oct. 17	*Nov. 14*	*Dec. 12*	*Jan. 9*	*Feb. 6*	*March 6*	*April 3*	*Season mean*
•Crude protein.	13·94	12·35	11·29	13·59	12·66	13·75	13·80	13·05
Ether extract	3·20	3·05	2·80	2·77	2·25	3·20	2·45	2·82
N-free extractives	49·54	49·52	49·19	46·40	51·16	49·97	50·77	49·51
Crude fibre	25·52	27·57	30·51	31·33	29·22	28·40	28·23	28·68
†Ash	7·80	7·51	6·21	5·91	4·71	4·68	4·75	5·94
•Including: True protein.	11·78	10·08	8·94	11·32	10·52	11·31	12·19	10·88
†Including: Phosphoric acid (P_2O_5)	0·897	0·753	0·845	0·909	0·845	0·839	0·763	0·836
Lime (CaO)	0·814	0·618	0·826	0·858	0·612	0·562	0·602	0·699
Digestibility of crude protein (Wedemeyer)	76·20	68·04	53·69	52·65	58·16	61·22	64·70	62·01
True/crude protein ratio	0·85	0·80	0·79	0·83	0·83	0·82	0·89	0·83

PLOT B (grazed)

•Crude protein.	13·32	14·31	13·23	12·91	14·08	13·83	15·06	13·82
Ether extract	3·22	3·03	2·87	2·90	2·04	2·05	1·84	2·57
N-free extractives	50·45	48·44	47·22	47·92	50·70	50·77	52·00	49·64
Crude fibre	25·67	26·90	30·22	30·26	27·61	28·18	26·14	27·85
†Ash	7·34	7·32	6·46	6·01	5·57	5·17	4·96	6·12
•Including: True protein.	11·76	11·83	10·23	11·32	12·40	12·02	13·39	11·85
†Including: Phosphoric acid (P_2O_5)	0·848	0·883	0·813	0·914	0·928	0·809	0·831	0·861
Lime (CaO)	0·912	0·832	0·796	0·678	0·480	0·536	0·766	0·714
Digestibility of crude protein (Wedemeyer)	69·52	61·77	57·85	54·34	61·67	58·24	63·10	60·93
True/crude protein ratio	0·88	0·83	0·77	0·88	0·88	0·87	0·89	0·86

In the absence of replicated treatments it was impossible to determine the variance due to soil heterogeneity in a direction at right angles to the main axes of the plots. As the experimental site was chosen with care, and as there was no reason to suppose that such soil heterogeneity existed, the validity of the conclusions drawn from comparisons made between the two treatments is unlikely to be affected.

The observed effects of season and treatment on some of the principal constituents of the grass, and the significance of such effects, are briefly summarized below:

Crude protein.—The crude-protein figures have proved to be less satisfactory than those for any other single constituent with the possible exception of phosphoric acid, in that replicate samples showed consider-

able variation. From an inspection of the means it would appear that, on the ungrazed plot, there was a decline between Oct. 17 and Dec. 12, followed by a marked increment in January. Thereafter, the crude-protein content remained substantially constant until the end of the period. On the grazed plot the protein followed a somewhat similar course, but sharp increases occurred between the first and second and the sixth and seventh cuttings. The means for the whole winter period showed a difference of 0·77 per cent. in favour of the grazed plot. The digestion-coefficients were very consistent on both plots, falling to a minimum in January and rising thereafter.

True protein.—During the first half of the winter there was a fairly well-marked fall in the percentage of true protein present in the grass from both plots, a minimum being reached in December. This decline was accentuated in the ungrazed herbage.

In both cases the ratio of true to crude protein fell during early winter and reached a minimum in December, rose sharply during January, and afterwards showed little variation.

Crude fibre and ether extract.—The percentage of crude fibre in the herbage of both plots rose markedly to a maximum in December. On the ungrazed plot there was an apparent decline from January; under grazing the fibre followed a similar course, except that a temporary increase occurred in the samples of March 6. With one exception (Oct. 17), the ungrazed plot has shown a higher fibre-content on every cutting occasion, the seasonal mean being greater than on the grazed plot to the extent of nearly one per cent.

The ether extract of the ungrazed herbage fell consistently between October and February, but rose sharply in March to fall again in April. On the other plot this constituent declined from the beginning to the end of the winter period with some regularity, although there were checks during the periods Dec. 12—Jan. 9 and Feb. 6—March 6. The difference between the seasonal means for the two treatments was 0·25 per cent.

Ash and ash-constituents.—The soil-free ash of the ungrazed grass fell consistently until Feb. 6, this decline being of undoubted significance; during the rest of the winter period it continued at a low level. From a study of the means it is obvious that the phosphoric-acid content of grass from this plot did not vary to any considerable degree during the winter. The agreement between replicates was, however, not close enough to warrant any conclusions as to the significance of the relatively small differences between means. The mean lime-content appears to show some irregularity, but no real decline occurred until after Jan. 9; from Feb. 6 onwards it must be considered to have remained constant at a lower level.

On the grazed plot there was a steady fall in the amount of soil-free ash present from Nov. 14 until April 3, the difference between the ash-contents on these two dates being very large. The mean values for phosphoric acid on this plot were similar to those obtained on the ungrazed land, and for the reasons given above, no significance can be attached to the small differences found. There was a regular fall in

lime-content from the beginning of the winter until Feb. 6; the following two cuttings showed a sharp rise. The seasonal means for ash, phosphoric acid, and lime were not disparate as between the grazed and ungrazed plots, although they were slightly higher on the former.

Discussion

The results shown in Table 2 indicate that grass produced under the conditions of this experiment retained an unexpectedly high feeding-value, even after exposure to several months of wintry weather. Indeed, the mid-winter samples compare not unfavourably with month-old grass from many of the poorer Boulder Clay pastures, and are apparently superior to still younger grass from unimproved land of the type represented by Plot 6 of Tree Field and untreated areas of Paradise at Cockle Park. Thomas and Elliott [6] showed that out of twelve fortnightly samples taken from the former during the growing season of 1930, only two contained more than 9·0 per cent. of crude protein, and the phosphoric acid exceeded 0·5 per cent. on only one occasion. It would be rash to dogmatize in the absence of complete digestibility data, but large differences like those noted above would probably suffice to balance, or even outweigh, the reduced digestibility of the winter grass.

The Roundabouts Field, on which the experiment was conducted, might be described as a well-managed Boulder Clay pasture, and is undoubtedly in a high state of fertility. A good indication of the quality of the grass which it produces may be obtained from Table 3, which shows the composition of monthly samples taken during the growing-season of 1934.

TABLE 3. *Composition of Grass from Roundabouts Field, Cockle Park (1935). Percentage of Soil-free Dry Matter*

	May 2	*May 31*	*June 29*	*July 25*	*Aug. 24*	*Sept. 17*
*Crude protein	19·67	16·03	16·50	18·81	20·50	23·26
Ether extract	3·21	3·06	3·01	3·34	3·99	3·65
N-free extractives	48·69	49·70	50·98	46·08	45·85	42·61
Crude fibre	19·57	23·15	21·60	22·66	20·72	20·90
†Ash	8·86	8·06	7·91	9·11	8·94	9·58
*Including:						
True protein	16·57	13·22	14·96	14·80	16·74	19·19
†Including:						
Phosphoric acid (P_2O_5)	1·058	1·036	0·991	1·118	1·098	1·246
Lime (CaO)	1·298	1·419	1·534	1·598	1·431	1·368
Digestibility of crude protein (Wedemeyer)	74·68	79·39	66·38	75·47	74·72	78·58
True/crude protein ratio	0·84	0·83	0·91	0·80	0·82	0·82

In comparing winter and summer grass, it should be borne in mind that the former was approximately 2½ months old when the winter period opened on Oct. 17. As already indicated, the crude-protein content of the 'laid-up' grass remained at a useful level throughout the

winter; it was, nevertheless, substantially less than in summer grass of the age at which it is normally grazed. The digestibility of this constituent was also lower in the winter samples, although it did not fall to the extent anticipated, and was never less than 50 per cent.

The comparatively high mineral efficiency of the winter grass and the manner in which this efficiency has been maintained, at least in so far as the phosphoric acid is concerned, is possibly of greater interest than any other information which has emerged from this investigation. Throughout the winter the phosphoric-acid content never fell below 0·8 per cent. on the grazed plot, and was less than this figure on only two occasions where the grass was unstocked. Although the lime-content was satisfactory during the early part of the winter, later on it declined considerably. This decline started at an earlier date and was more marked on the grazed plot.

Although the mineral efficiency of the winter grass, as judged by its contents of lime and phosphoric acid, is certainly less than that of month-old summer grass, it would appear to be more than adequate for the needs of the classes of stock commonly out-wintered. The consistent decline in the ash-content during the winter suggests that other mineral constituents are more seriously depleted than the lime and phosphoric acid.

The crude-fibre content of the winter grass from both plots was markedly higher than that normally associated with summer growth, and the digestibility of this constituent had probably depreciated to a serious extent. Woodman and Oosthuizen [2] have shown that the digestion-coefficient of the crude fibre of grass laid up at the end of July and sampled early in December was 59·7 per cent., as against 83·7 per cent. in young spring grass from the same field.

Nevertheless, winter grass compares very favourably indeed with hay grown on similar land at Cockle Park which has been well done for many years. For purposes of comparison, Plot 12, Palace Leas, which has received an annual dressing of 300 lb. basic slag and 100 lb. muriate of potash per acre, and which has been shown to be one of the best plots on that field, may be used. The crude-protein content of the 1932 hay crop from this plot proved to be 9·53 per cent., and to have a digestion-coefficient of 74·91. The digestible protein therefore amounted to 7·13 per cent., as against seasonal means of 8·42 and 8·09 per cent. for winter grass from the grazed and ungrazed plots, respectively. The crude fibre was 31·12 per cent., as against 27·85 and 28·68 per cent. respectively. The lime-content of the hay (0·79 per cent.) was slightly higher than either of the seasonal means for the winter grass, but it may be noted that most of the cuts taken before Jan. 9, 1935, were actually superior to the hay in this respect. The hay appears to be definitely inferior to winter grass in respect of phosphoric acid, showing only 0·69 per cent. as against 0·86 and 0·84 per cent., respectively. Unfortunately no reliable data as to the weights of dry matter present on the experimental plots at the beginning of winter are available, but they were estimated to have been not less than 3,500 lb. per acre. In any circumstances a yield of 2,500 to 3,000 lb. might be expected from similar

Boulder Clay pastures which have been managed rather less efficiently. That substantial yields may be obtained from land laid up in late summer is indicated by results collected during recent years on experimental grassland plots at Cockle Park. In the season of 1930 the mean dry-matter yield from five plots on Tree Field, between July 23 and the end of the growing-period, was 2,234 lb. per acre, and constituted 56 per cent. of a total yield of 4,001 lb. secured from cuttings taken at intervals of fourteen days throughout the season (May 12–Oct. 13). Mercer [7] has stated that, on permanent grassland at Reaseheath, the yield for monthly cuts taken after June 20 amounted to approximately 60 per cent. of the total.

The cause of the rather marked seasonal variation in fibre-content, which has been shown to occur, is probably less obvious than it might seem. Woodman and Oosthuizen [2] have shown that the re-elaboration of material which sets in with the incidence of hard weather, and which is accompanied by lignification of the cellulose, raises the fibre-content to only a slight degree, although it has markedly depressing effects on digestibility. It is unlikely that the absolute amount of fibre present varies to the extent implied by the figures; the substantial increase in the fibre-content of the dry matter which occurs between October and January is probably, in part, a reflection of losses sustained by other constituents owing to the slowing down of photosynthesis. Despite the fact that the early winter of 1934–5 was not unduly severe, the climatic conditions at Cockle Park are such that this increase in fibre-content can hardly be ascribed entirely to maturation.

The decline in crude-protein content which appears to occur on both plots during the first months of the winter is probably due to evacuation from the foliage. The increasing proportion of non-protein nitrogen shown to be present indicates that hydrolysis is playing the major part in protein metabolism at this time of the year. Thomas [8], in a study of the nitrogen metabolism of apple trees, showed that, in autumn, there is migration of nitrogen from the leaves to the branches. At first sight the fall in true protein, and in the ratio of true to crude protein, appears somewhat surprising, but it may be explained as resulting from two causes. The degradation of protein prior to translocation of nitrogen from the leaves must be considered as responsible in some measure for the accumulation of non-protein nitrogen. The second factor concerned is low temperature. Harvey [9], after investigating the effect of frost and low temperature on various succulent plants, concluded that, although changes in the carbohydrate values are slight, the amino-acid content increases. In an investigation of the winter hardiness of wheat, Newton [10] found that all the varieties used in his experiments increased in amino-nitrogen and water-soluble nitrogen during hardening. It is possible to explain the very marked fall in the digestibility of the crude protein between October and January on the grounds that hydrolysis has been confined to the non-nuclear proteins. It follows that the ratio of so-called nucleo-proteins to total crude protein would rise. As the nucleo-proteins on digestion with pepsin are very incompletely hydrolysed, leaving an insoluble residue of protein combined with

nucleic acid, it is obvious that the digestion-coefficient of the crude protein, as determined by the method of Wedemeyer, would fall. The renewal of protein synthesis and growth early in the New Year accounts for the rise in digestibility which was first observed in the cutting of Feb. 6.

Reference has already been made to the consistent decline in the ash-content throughout the winter. As the phosphoric-acid content remains remarkably constant, and as the lime suffers serious depreciation only after January, it appears that the loss has fallen largely on ash-constituents not determined in the course of this work. The authors are not prepared to account for such loss, but suggest that one or both of two factors may be responsible: viz. (*a*) leaching, following severe frost damage or injury due to treading, (*b*) translocation. Woodman and Oosthuizen [2] have stated that the lime-content of grass is depressed by exposure to frost, and it is possible on these grounds to explain the marked decline in lime-content which occurred on both plots in early spring. It is noteworthy that the percentage of lime present fell sharply in the cutting of Nov. 14, which followed immediately after a series of ground frosts.

Much emphasis is laid on the selective action of stock in grazing, and it might reasonably be anticipated that any such selectivity as may be exercised would be reflected in the chemical composition of the sward, and that there would be an appreciable fall in the percentage of such constituents as crude protein, phosphoric acid, and lime. From a comparison of the relevant data in Table 2, it appears that the present experiment has afforded no evidence of selective grazing. The grazed plot actually shows somewhat higher seasonal means for protein, phosphoric acid, and lime, and a lower mean for crude fibre.

Summary

The effects of grazing, seasonal, and other factors on the composition of grass laid up for winter keep have been studied.

The crude-protein content of the grass declined between October and December on grazed and ungrazed plots alike, but rose again in late winter with the resumption of growth. The digestion-coefficients fell with great consistency to a minimum in January and rose thereafter, the decline being accentuated on the ungrazed herbage. A similar fall in early winter was shown by the ratios of true to crude protein. An attempt has been made to give some physiological explanation for the changes which have occurred in the nitrogen constituents of the dry matter.

Seasonal changes in the crude-fibre content of grass from both experimental plots were essentially similar, maxima being reached in January.

Ether extract follows the same general trend under both treatments, and the amounts declined with some regularity throughout the winter.

On both plots the ash-content showed marked seasonal variation, falling steadily from the beginning to the end of the experimental period. This loss of mineral matter was not due to any decline in the phosphoric-acid content. It is suggested that losses sustained by the lime and by

ash-constituents not determined in the course of this work can be attributed to translocation and leaching, the latter possibly following on injury due to frost or other causes.

The nutritive value of winter grass, as judged by its chemical composition, is inferior to that of summer grass from the same pasture and of an age at which it is normally grazed. Nevertheless, the mineral efficiency of the winter grass was comparatively high, and it compared favourably in this and other respects with month-old summer grass from inferior Boulder Clay pastures, and with hay from one of the best meadow plots at Cockle Park.

The present experiment has failed to provide evidence of selective grazing by out-wintered stock.

It is suggested that the practice of laying up grass for winter keep affords a useful means of conservation which might be more widely employed in districts enjoying moderate conditions of climate.

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EXPERIMENTS ON THE GROWING OF CHICORY (FOR DRYING)

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THE erection of a factory for drying chicory at Needingworth, near St. Ives, Huntingdonshire, afforded an opportunity for farmers and small-holders in the district to introduce another cash crop, grown on contract at a fixed price, into their crop rotation. In view of the interest shown in the cultivation of the crop, some experiments were carried out in the district in the seasons 1932, 1933, and 1934 with a view to ascertaining if the crop had any special manurial requirements, and in what respects, if any, its treatment should differ from that adopted for a crop such as sugar-beet.

The soils on which most of the crop is grown are gravelly loams and fens, owing to the difficulty of lifting such a deep-rooting crop on heavy soils. For this reason the experimental centres were situated on these two types of soil.

The condition or 'heart' of the soils at the experimental centres, as judged by past history and soil analysis, was reasonably good and fairly representative of much of the land on which chicory is usually grown in the district. Striking responses to manurial treatment could not therefore be expected, nor were they obtained in practice, though this fact must not be interpreted as indicating the likelihood of a similar small response on soils in a low state of fertility or in a different district.

The results obtained are described below under the three headings: Manuring, Spacing, and Effects of Soil Acidity.

In all cases the experimental plots were arranged either in Latin squares or randomized blocks, each treatment being replicated at least four times at each centre. At most centres individual plots were from 1/80th to 1/100th acre. In the spacing trials, the three singling-distance sub-plots were randomized over each main row-width plot, and hence were only one-third of this area.

Experiments on the Manuring of Chicory

Four centres were situated on light soils, three being on gravelly loams and one (Centre 3) on light sand. Centres 1 and 4 were on fields which had been well cultivated and liberally manured for some years, and their yields of chicory may be taken as a fair example of what can be grown on such land when properly cultivated.

Centre 2 was on land which was not in such good heart as the other two gravel-loam centres, neither was the land as clean, for despite a bare fallow in the previous year, the 1933 chicory crop suffered very

considerably from weed-competition. The harmful effects of this weed-competition were accentuated by very dry weather immediately after seeding, and indeed right up to singling-time, which considerably delayed that operation. The weed-growth during this period also rendered singling much more difficult and increased the loss of plant at this stage, as will be seen from the fact that, with rows 16 in. apart, the average plant-population was only 25,000 per acre. Despite the low average yield at this centre it will be seen from Tables 1 and 2 that the response to

TABLE 1. *Effect of Nitrogen, Phosphorus, and Potassium Yield of Chicory (tons per acre)*

	Centre 1 1934	*Centre 2 1933*	*Centre 3 1933*	*Centre 4 1932*	*Centre 5 1933*	*Centre 6 1932*
NPK	13·71	7·2	6·6	10·45	18·25	8·70
NP	13·96	6·4	6·25	10·45	18·15	9·40
NK	14·59	6·65	6·2	11·02	18·35	8·71
PK	13·50	7·0	6·1	10·30	18·0	9·0
Nil	13·67	6·8	5·55	9·68	17·7	9·30
Standard error	0·51	0·37	0·7	0·84	0·67	0·39

N.B.—(1) N = Nitro-chalk at 3 cwt. per acre in two equal doses.
P = Superphosphate at 3 cwt. per acre.
K = Muriate of potash at 1½ cwt. per acre.
(2) The 1932 figures are actual factory-washed weights; the other figures are yields of roots knocked as clean as possible in the field but not washed.
(3) No dung was applied for the chicory crop at these six centres.
(4) At all centres the effect of treatment was insignificant when tested by Fisher's '*z*' test.

artificial fertilizers was relatively small, and that the response to 3 cwt. of nitro-chalk was no greater than the response to 1½ cwt., a fact suggesting that the effect of fertilizers was here limited by the generally unsuitable soil conditions and by the irregular plant left after singling. The effect of the unsatisfactory plant and the delay in singling may be seen by comparison with the results obtained in a spacing trial on an adjacent strip of land in the same field (Centre 7, Table 3). The spacing trial, though sown on the same day, was singled earlier and more carefully than the manurial trial, and even on 18-in. rows 27,000 plants per acre were obtained on the widest (12 in.) singling, which resulted in a yield equal to the average of the manurial trial, the yield increasing very rapidly with closer spacing.

A similar low response to fertilizers, despite a low average yield, will be seen in the case of Centre 3, and here again dry soil conditions, combined with patches of twitch, and slight soil acidity (an application of lime was made for the chicory crop but not early enough in view of the dry weather), resulted in a somewhat irregular plant and a final crop yield considerably below that obtained on an adjacent spacing trial (Centre 8, Table 3), where a full plant was obtained and soil conditions were generally more favourable.

Two centres, numbers 5 and 6, were situated on black fen land, the former having the better soil of the two. A third fen-land centre had to

be abandoned owing to loss of plant due to wind-storms while the crop was in the seedling stage. The low yield at Centre 6 was again probably due, in part at any rate, to lack of care at singling. The higher yield at Centre 5 is more typical of what can be obtained on good fen soil, bearing in mind that no deduction for dirt tare was made in the weights at this centre. A point of interest at Centre 5 is that, with rows 16⅜ in. apart, the average plant-population was 48,844 per acre, and the average root-weight was maintained at the satisfactory level of 0·85 lb.

None of the fertilizer treatments gave statistically significant increases in yield of chicory. On light soils (Centres 1 to 4) the application of a complete fertilizer supplying nitrogen, phosphorus, and potash gave a small increase in yield over the unmanured plots, the average increase being 11¼ cwt. per acre. The omission of nitrogen or potash from the complete fertilizer resulted in a slight reduction in yield—approximately 5 cwt. per acre in each case, whilst the omission of superphosphate caused no reduction at Centres 1 and 4, but a reduction of nearly 10 cwt. per acre at Centres 2 and 3, which were known to have been less liberally treated in this respect in recent years.

It does not appear likely, therefore, that on soils in a normal state of fertility, the chicory crop has any very pronounced requirement for one element of plant-food more than for any other; neither does it respond very markedly to heavy applications of complete artificial fertilizers in such circumstances.

The results obtained in experiments dealing with the quantity and time of application of the nitrogenous part of the fertilizer mixture, carried out on the same four light-land farms, are shown in Table 2.

TABLE 2. *Yield of Chicory* (*tons per acre*)

Nitrogenous manuring	*Centre 1 1934*	*Centre 2 1933*	*Centre 3 1933*	*Centre 4 1932*
3 cwt. per acre Nitro-chalk before seeding	14·13	7·4	6·5	11·11
1½ " " " " " " at singling	13·71	7·2	6·6	10·91
1½ " " " " before seeding	14·22	7·4	6·6	11·08
No Nitro-chalk	13·50	7·0	6·1	10·39
Standard error	0·51	0·37	0·7	0·15

N.B.—The effect of treatment was only significant by Fisher's '*z*' test at Centre 4, where all three nitrogenous treatments gave significantly higher yields than plots receiving no nitrogenous fertilizer.

It will be seen that no yield-increase was obtained beyond that for the first 1½ cwt. per acre of nitro-chalk, no matter whether the additional application was made prior to seeding or at singling time.

As in the case of sugar-beet, chicory is reputed to respond well on the Continent to heavy dressings of artificial fertilizers, but it appears that, in the present state of our knowledge of the cultivation of the crop in this country, other factors, such as soil tilth, plant-population, and weather conditions may frequently be of greater primary importance. It should be borne in mind, however, that in two of the seasons under review

the dry weather conditions during the summer months tended to reduce the availability of artificial fertilizers applied direct to the crop, especially those applied as late top dressings.

Experiments on the Spacing of Chicory

Centres 7 and 9 were on gravel-loam soils and Centre 8 on a light sandy soil. The desired row-widths were obtained in all cases, but at singling time the workers were instructed to single the plants as closely as possible to the desired distances, only the first few plants in each case being accurately measured. Hence the final crop was rarely spaced with

TABLE 3. *Experiments on the Spacing of Chicory*

Row-width (in inches)	*Singling-distance (in inches)*	*Actual no. of plants per acre in thousands*			*Yield in tons per acre*			*Yield referred to 18 × 12 in. work as 100*			*Average weight per root (in lb.)*		
		Centre			*Centre*			*Centre*			*Centre*		
		7	8	9	7	8	9	7	8	9	7	8	9
18	12	27	31	33	6·7	9·4	8·9	100	100	100	0·6	0·7	0·7
18	9	28	36	38	6·9	9·9	9·5	102	106	107	0·6	0·6	0·6
18	6	34	41	42	7·4	9·8	8·7	111	104	99	0·5	0·6	0·4
15	12	30	43	43	10·0	9·8	10·4	148	105	117	0·7	0·5	0·6
15	9	36	42	48	10·5	8·7	10·9	156	93	123	0·7	0·5	0·6
15	6	40	58	51	9·5	10·5	11·0	141	112	124	0·5	0·4	0·5
12	12	41	46	57	10·0	9·2	11·3	148	98	127	0·6	0·5	0·5
12	9	47	54	54	12·2	10·3	11·5	182	110	130	0·6	0·5	0·5
12	6	62	63	61	14·4	11·4	12·1	214	121	136	0·5	0·4	0·5

SUMMARY OF SPACING RESULTS

(*a*) Relative yields referred to 18-in. rows as 100

	Centre 7	*Centre 8*	*Centre 9*
On 18-in. rows—mean of all singling distances =	100	100	100
„ 15-in. „ „ „ =	142	100	119
„ 12-in. „ „ „ =	174	106	129
Standard error . . . . . =	2·5	3·2	2·1

(*b*) Relative yields referred to 12-in. singling as 100

	Centre 7	*Centre 8*	*Centre 9*
With 12-in. singling—mean of all row-widths =	100	100	100
„ 9-in. „ „ „ =	111	102	104
„ 6-in. „ „ „ =	117	112	104
Standard error . . . . . =	6·7	4·4	1·9

Despite considerably higher yields obtained in conjunction with close singling, the effect of singling-distance was not statistically significant, nor was the interaction between singling-distance and row-width. Narrow rows gave significantly higher yields than wide rows at Centres 7 and 9, but not at Centre 8.

any great precision, but represented rather the plant-distribution which would be obtained in farming practice when attempting to achieve the different spacings. The 6-in. spacing, as might be expected, was most difficult to obtain, and it is noteworthy that the accuracy at this spacing was no greater on rows 18 in. apart than on rows only 12 in. apart. Nine-inch spacing was achieved with fair accuracy on all row-widths at Centres 8 and 9, but not so well at Centre 7. Twelve-inch spacing was obtained on the 18-in. rows, but the plants were left rather too close at all centres on the narrower row-spacings.

The results indicate the importance of close spacing if high yields are to be obtained, especially as regards row-width. Close singling proved even more important at all centres on narrow (12 in.) rows than on wide (18 in.) rows.

The whole question of the effect of plant-population on crop yield is surrounded by many difficulties, as in the sugar-beet crop, but the results obtained in these experiments on chicory bear out Continental experience as to the importance of narrow spacing, and it is suggested that where practical considerations permit, the row-width for chicory should be not more than 15 in. and the singling-distance not more than 9 in. This is closer spacing than is usually adopted for sugar-beet, and necessitates careful work with implements and a considerable amount of hand labour, but where this is available, as on smallholdings, the increase in yield can reasonably be expected to compensate for the additional time and labour.

Effect of Soil Acidity on Growth of Chicory

Observations such as those made at Centre 3 demonstrated the reduction in plant-population, vigour of growth, and final yield of chicory consequent on soil acidity.

In a long-term liming experiment, established in December 1931 by one of the writers in co-operation with Mr. J. W. Dallas, Agricultural Organizer for Bedfordshire, chicory was sown in the season 1933. The results obtained showed statistically significant increases in the yield of chicory on the limed plots. Details of the soil analysis and yields of chicory are shown in Table 4.

TABLE 4. *Effect of Soil Acidity on Yield of Chicory*

Soil: loamy sand (clay 10 per cent., sand 67 per cent.).
Exchangeable calcium (per cent. CaO) = 0·07 per cent.
Hutchinson & McLennan lime-requirement: 0·19 per cent. $CaCO_3$ (pH value = 5·9).
Yield of chicory on limed plots: 10 tons 13 cwt. per acre.
" " " unlimed plots: 8 tons 13 cwt. per acre.
Standard error: 11 cwt. per acre.

General experience seems to indicate that in its susceptibility to the harmful effects of soil acidity, chicory is very similar to sugar-beet.

Conclusions

1. Experiments conducted during the years 1932, 1933, and 1934 failed to show any large response by the chicory crop to applications of complete artificial fertilizers, and no special requirement by the crop for any one particular element of plant-food more than any other on soils in a normal state of fertility. No evidence was obtained to support the practice of withholding part of the nitrogenous dressing till singling time, and it is suggested that a moderate dressing of a complete fertilizer, such as that commonly used for the sugar-beet crop growing under similar conditions, is suitable for the chicory crop, the whole application being worked into the soil prior to seeding.

2. Spacing trials showed that considerable increases in yields were obtained where close spacing was adopted. Although these trials are

open to the criticism that the spacings attempted were rarely obtained in practice and the data therefore represent the results of a somewhat irregular plant-population, they do indicate the importance of close spacing. The effect of row-spacing was particularly pronounced, and whilst realizing the practical difficulties sometimes involved, it is suggested that the spacing adopted for chicory should certainly be closer than for the sugar-beet crop—a fact which itself suggests the suitability of the crop for smallholdings rather than extensive farming conditions.

3. Soil acidity has been shown to cause serious reduction in the yield of the chicory crop.

4. On gravel-loam soils in normal condition, average yields of 10 tons per acre of chicory roots can be obtained under ordinary farming conditions. On good fen soils yields should reach 15 tons per acre.

5. Experience gained in the course of these trials has shown the great importance of careful preparation of a good seed-bed and early and careful singling of the crop.

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